ROBUST MULTI-SCENARIO OPTIMIZATION OF AN AIR EXPEDITIONARY FORCE FORCE STRUCTURE APPLYING SCATTER SEARCH TO THE COMBAT FORCES ASSESSMENT MODEL

THESIS

Gokay Bulut, 1st Lieutenant, TUAF

AFIT/GOR/ENS/01M-05

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GOR/ENS/01M-05

ROBUST MULTI-SCENARIO OPTIMIZATION OF AN AIR EXPEDITIONARY FORCE FORCE STRUCTURE APPLYING SCATTER SEARCH TO THE COMBAT FORCES ASSESSMENT MODEL

THESIS

Presented to the Faculty

Department of Operational Sciences

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Operations Research

Gokay Bulut, B.S.

1st Lieutenant, TUAF

March 2001

AFIT/GOR/ENS/01M-05

ROBUST MULTI-SCENARIO OPTIMIZATION OF AN AIR EXPEDITIONARY FORCE FORCE STRUCTURE APPLYING SCATTER SEARCH TO THE COMBAT FORCES ASSESSMENT MODEL

Gokay Bulut
1st Lieutenant, TUAF

Approved:

Raymond R. Hill	2 Mar 01
Lt Col Raymond R. Hill (Chairman)	date
James T. Moore	2 Mar 01
Dr. James T. Moore (Member)	date
Gregory A. McIntyre	2 Mar 01
Lt Col Gregory A. McIntyre (Member)	date

Acknowledgments

First of all, I would like to thank my faculty advisor, Lt Col Ray Hill for his guidance, support, and patience throughout the course of this thesis effort. I especially appreciate his help on the use of English in a research paper. My readers, Dr. James Moore and Lt Col Greg McIntyre, also contributed with their insight and experience. This was certainly appreciated. I would also like to thank Capt Lance Champagne from the Department of Operational Sciences, for his assistance with the Combat Forces Assessment Model.

I would also like to thank my sponsors, the Air Force Studies and Analyses Agency and the Dayton Area Graduate Studies Institute, for their support.

Finally, I would like to express my appreciation to my country for the opportunity to get a Master's degree in an enjoyable foreign country thousands of miles away. Since words cannot adequately express my thanks, doing my best in follow-on assignments will be my way of thanking.

Gokay Bulut

Table of Contents

Page

List of Figures

List of Tables

Page

AFIT/GOR/ENS/00M-05

Abstract

'Modern Times' bring change in all areas of life. Even the rate of change has changed and is still changing to increase its enormous speed even more. Newer and more challenging questions face the military analysts everyday putting a question mark at the end of their last answer. Recently, the question of how to structure a robust air force to meet the requirements of competing, uncertain future scenarios has been keeping analysts busy. The new world order does not tolerate only being able to respond to a single scenario anymore, which once was considered a hard problem. Who knows what comes next?

In this thesis, we employ a robust optimization methodology to provide an answer to the multi-scenario optimization problem. The methodology uses a meta-heuristic, Scatter Search, to guide the search of the multi-scenario solution space obtained by the evaluations of Combat Forces Assessment Model, the model currently used to respond to single theater scenario objectives. A Visual Basic\DOS routine performs the necessary interactions to find an Air Expeditionary Force structure robust across three notional threat scenarios.

ROBUST MULTI-SCENARIO OPTIMIZATION OF AN AIR EXPEDITIONARY FORCE FORCE STRUCTURE APPLYING SCATTER SEARCH TO THE COMBAT FORCES ASSESSMENT MODEL

I. Introduction

Thesis Overview

This chapter starts with a brief description of the multi-scenario optimization problem including its background, and continues with brief discussions of the research objectives, approach methodology, and scope of the thesis. Chapter Two provides information from the current literature about the tools and methodologies that address the multi-scenario problem while Chapter Three discusses our research methodology. Chapter Four presents a comparison of our test results to those of a previous study in this area. The final chapter discusses the research findings and proposes recommendations for further research.

Background

Today's amazingly fast changing world presents the military with the challenge of being ready for an unexpected crisis situation anytime, anywhere since this unexpected situation would not just affect the countries involved. Such situations would have global consequences. Thus, many military planners have been trying to answer the main

question of this readiness problem: How to build a force structure with the necessary equipment to best meet all of the competing requirements of different, uncertain, future scenarios. Clearly, to have a huge force to guarantee the best outcome in all potential conflicts is not an option due to the tremendous cost. The answer lies in finding a way to size a robust force structure across the range of uncertainty represented by the scenarios. The term *robust* refers to being stable under different conditions, or not showing a difference in the output when the inputs are changed slightly. So, we need to find that force structure which meets the objectives of all the scenarios.

One proposed solution pertains to the US Air Force's restructuring into an expeditionary aerospace force (EAF) with ten aerospace expeditionary force (AEF) units containing 120-150 aircraft. The foundational question for this research is how to determine the aircraft and weapons mix that are best for an AEF.

Problem Statement

To meet the Air Force's need to be prepared for any situation anytime, analysts need a methodology to determine force structures that are robust across uncertain future scenarios. Specifically, for our test case, the number and type of aircraft and munitions needed to form the force structure must be determined. The problem is how to size a suitable force to meet the uncertain demands of future scenarios. We propose a methodology for finding robust solutions to military force planning problems. Our focus will be on building an air expeditionary force structure that is robust across three notional scenarios. The research using the existing Air Force Studies and Analyses Agency's

(AFSAA) model CFAM (Combat Forces Assessment Model) to evaluate the force structure.

Research Objective

The objectives of this thesis are to develop and apply a methodology for structuring an air expeditionary force robust across a variety of scenarios, compare the results with previous work accomplished in the same area; and identify alternative ways to better examine the solution space before coming to any firm conclusions. In addition, the methodology is demonstrated in a way applicable to realistic large-scale problems of the same type. Thus, our methodology may aid in planning and budgetary exercises.

Approach Methodology

This thesis employs Scatter Search, an advanced heuristic search procedure, to guide the use of the Conventional Forces Assessment Model to evaluate the effectiveness of candidate force structures across the multi-scenario space. The methodology terminates with robust solutions. The basic research approach is diagramed in Figure 1.

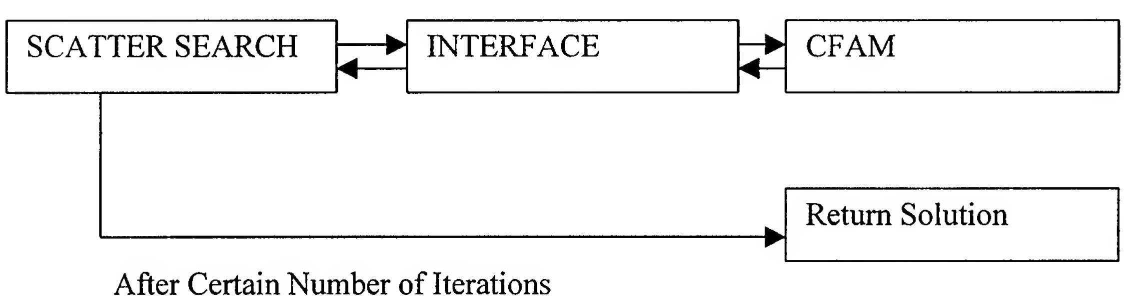


Figure 1. Basic Research Approach

The interface performs necessary interactions between the meta-heuristic and the combat model. First, it runs CFAM with a candidate solution suggested by Scatter Search. For each scenario run in CFAM, outputs are transformed into a scenario evaluation. After performing this evaluation three times (one for each scenario), the interface combines the evaluations into a single weighted objective function value, which it passes back to the meta-heuristic to continue the search of the unexplored solution space. The cycle stops after a specified number of iterations or when convergence to a global optimum is detected.

Scope

This thesis considers an AEF sized notional force structure tasked against three potential, seven-day duration, small-scale contingency (SSC) scenarios for the comparison of two heuristic search methods, the Scatter Search and Bennett's GA (Bennett, 2000) applied to a multi-scenario optimization problem. Therefore, Bennett's settings are used. Bennett selected an AEF structure because of the U. S. Air Force EAF emphasis and considered the SSC instead of a MTW (major theater war) due to its increased likelihood of occurrence (Bennett, 2000:9). To measure the effectiveness of candidate force structures, the combat model currently in use by the US Air Force, CFAM, is used as the evaluator. The problem is chosen to be relatively small because of the long processing time of CFAM runs, assuming the methodology can be scaled up to meet the requirements of real life scenarios.

II. Literature Review

Introduction

To address the multi-scenario optimization problem, solution techniques available in the operations research literature are employed. Some of these are covered in this section. Beside heuristics, there also are other optimization techniques such as exploratory analysis, robust optimization, scenario analysis, stochastic modeling, and graceful degradation.

Heuristic Search Methods

A heuristic search method is a technique used to solve optimization problems, which seeks good (*i.e.* near optimal) solutions at a reasonable computational cost. According to Nicholson, it is a procedure "… for solving problems by an intuitive approach in which the structure of the problem can be interpreted and exploited intelligently to obtain a reasonable solution" (Nicholson, 1971:111). According to Muller-Merbach, the term heuristics is usually understood in the sense of an iterative algorithm, which does not converge toward the solution of a problem (Muller-Merbach, 1981:1-23).

A *meta-heuristic* is used to define master strategies modifying other search procedures to find solutions other than those that are produced while searching for local optima. To answer the question why take a meta-heuristics approach in solving multi-

scenario optimization problems, some additional terms in regards to complexity theory need to be defined.

A problem is said to be solvable in *polynomial time* if its solution algorithm has a worst case running time with $O(n^k)$, *i.e.* an asymptotic upper bound of (n^k) where n is the problem size and k is some constant. These problems are considered easy to solve as their solution times are considered reasonable. However, many practical optimization problems do not have solution algorithms guaranteed to complete in polynomial time. For these harder problems, other solution techniques are required.

Heuristics are powerful alternatives when an analytic solution to a problem does not exist or is computationally too expensive to find. In addition, they are often easy to implement. Although heuristics do not typically give an optimal solution, they locate reasonably good solutions very fast. They also deal with the real problem versus an approximation of reality with strong assumptions. The following discusses examples of heuristic search methods:

Genetic Algorithms (GAs)

"Genetic algorithms are a new artificial intelligence paradigm that arose from the investigations of cellular automata in 1970s" (Buckles and others, 1990:28). The formal theory was developed by John Holland and in recent years has been applied to problems as diverse as pattern recognition and optimization. According to Webster's dictionary (Kryger and Bubriski, 1999:485), the word *genetic* means "of or relating to or involving genetics," where genetics is a branch of biology that deals with the heredity and variation of organisms.

Genetic algorithms (GAs) function by applying an analogy of genetics. A GA is a population based heuristic where good solutions, or *chromosomes,* survive into a new population to form a better *generation* in terms of overall quality of solutions. The set of solutions to a problem, making up a population, are also called *vectors*, or *strings* that consist of variables, or *genes*. Applying GAs to rule-based classifier systems, Holland gives an example of a basic execution cycle (the 'central loop') as follows:

1. Select pairs from the set of classifiers according to strength--the stronger the classifier, the more likely its selection.
2. Apply genetic operators to the pairs, creating 'offspring.' Chief among the genetic operators is crossover, which simply exchanges a randomly selected segment between the pairs.
3. Replace the weakest classifiers with the strongest offspring.

The effect of this procedure is to emphasize various combinations of defining elements -schemata- as building blocks for the construction of new, better solutions (Holland, 1986:42).

The solutions are encoded, usually in *binary coding,* which most resembles genetic DNA structure. The *genotype* is the structure of the solution used by the GA while *phenotype* is the physical expression of that structure. For example, the phenotype of the number 8 has a genotype of (1000) in 4-bit solution space while the phenotype of 7 has a genotype of (0111).

A GA starts with an initial population. We can create an initial population by randomly selecting the 0-1 values of genes in each solution. Another method is to use another heuristic to obtain better than random members. However, this approach

increases the possibility of premature convergence, *i.e.* we end up with a local optimum early in the procedure.

Selecting parents for mating requires a choice rule. The fitness value of an individual can be divided by the total population fitness value and used as a probability of parent selection. These approaches use fitness values. A specific proportional selection method, roulette wheel selection, assigns each individual a probability proportional to its fitness value. In rank selection, chromosomes are indexed by increasing fitness value with selection based on the index. The chromosome with the greatest index has the highest probability of selection for reproduction or mating. According to Grefenstette and Baker, the primary advantage of ranking over proportional selection is that the resulting algorithm is less prone to premature convergence caused by individuals that are far above average. (And, one might argue, selection by ranking seems closer to the mechanism of natural selection). A number of other alternative selection algorithms have also been studied by researchers such as Whitley, Goldberg, and Baker, but have not enjoyed the same level of theoretical analysis as the proportional selection algorithm (Grefenstette, 1999:127). One of them, tournament selection, is a method where the best of randomly selected parents are retained for production. The common element of these selection methods is a focus on providing better solutions a greater chance of survival, either directly or via a mating process yielding offspring containing characteristics of the 'good' parents.

Once parents are selected, offspring are generated. Offspring are generated by *crossover* and *mutation operators*. Both operators have a possibility of occurring. The crossover operator exchanges some parts of parent strings determined by a probability.

For example, suppose we have a randomly selected crossover point of gene location 3 with P_1=(1001**011**) and P_2=(0101**010**) as selected parents. Crossover, yields the offspring (1001010) and (0101011). This operator provides a means of *exploitation*, *i.e.* makes the algorithm intensify on a certain region of solution space. This is because more fit chromosomes will survive and get selected for mating. Then, the crossover operator will generate new solutions from these fit chromosomes giving the offspring the characteristics of the good parents. Here, higher fitness values may be found, but there is a high probability of getting stuck with local optima.

Crossover serves two complementary search functions. First, it helps the search examine new points within the hyperplanes already represented in the population. Second, it introduces points from new hyperplanes into the population. By evaluating a string of length *n*, we gather information about the fitness of the 2^n hyperplanes represented by that string. GAs are so powerful mainly because they exploit efficiently this vast amount of accumulating knowledge by means of relatively simple selection mechanisms (Grefenstette, 1986:122-128).

The mutation operator changes a randomly selected gene of a chromosome. For instance, a mutation at gene location 3 would produce (10**1**1010) from (10**0**1010). This operator gives rise to *exploration, i.e.* moves the search to other regions of the search space.

A new generation is formed by some combination of parents and offspring. Each new generation can replace the old generation *en bloc*, called generational replacement, or incrementally, where members are *killed*, or removed, according to their *fitness value* (usually the objective function value).

The fundamental theory of GA is the schema (plural: schemata) theorem. A schema is a general set of chromosomes having some genes in common. For example, the chromosomes 1111 and 1001 are instances of the schema 1**1, where * is 0 or 1. This schema has a *length* of three (the distance between first and last non-* genes) and an *order* of two (number of non-* genes).

We know that the most fit chromosomes are selected for mating and are carried over to the next generations. Each time we evaluate the fitness of a given chromosome, we are gathering information about the average fitness of each of the schemata of which that chromosome is an instance. We implicitly make use of this information to search for a best-fit schema, which has certain inherent solution quality attributes that survive generation replacements.

GAs prefer short, low order schema. The distance between short and low-order schemata's first and last non-* genes is small making it less likely to get separated by a crossover operator. Being less likely to break, short and low-order schemata will be carried over to the later generations (This assumption is called 'the building block hypothesis'). Thus, these schemata are preferred since they have a high probability of survival. Holland comments "Genetic algorithms, using the strength as 'fitnesses,' offer subtle ways of discovering good building blocks, and there are new versions of theorems from mathematical genetics that enable us to understand this discovery process" (Holland, 1986:101).

The genetic algorithm continues for a specified number of generations or until population convergence is detected. Beasley and Martin define convergence as, "A gene is said to have converged when 95% of the population share the same value. The

population is said to have converged when all of the genes have converged" (Beasley and Martin, 1993:58-69). They also claim that a properly designed GA will converge to the global optimum, by the principle of survival of the fittest. Even simple GAs have been reported to find good solutions faster than most other general solution techniques. The application of survival of the fittest means, only good solutions are kept and by searching a sufficient amount of the solution space, we will end up with a very good solution, if not the global optimum.

Empirical studies show that some important parameters in designing a GA are: crossover and mutation rates, population size, population initialization, and parent selection. High rates (0.8, 0.9) for crossover and low rates for mutation (0.02,0.03) are found to yield good solutions. In addition, seeding the population with solutions provided by other heuristics yield better results than random initialization (Grefenstette, 1986:122-128).

For population size, 30 is recommended as well as a value between n and 2n by Alander, where *n* is the number of variables (Alander, 1993:65-70). However, Holland's n^3 estimate is the most frequently cited theoretical development related to population size. Goldberg states "Simply stated, this computation says that the number of schemata processed effectively (those processed with an error rate less than a specified value) is proportional to the cube of the population size- is n^3"(Goldberg, 1989:117). His research suggests that relatively small populations are appropriate for serial implementations and large populations are appropriate for parallel GAs.

GAs are very domain independent, *i.e.* many problems can be encoded and solved by computerized GAs regardless of the original problem. De Jong reports, "Much of the

interest in genetic algorithms is due to the fact that they provide a set of efficient domain-independent search heuristics... There is now considerable evidence that genetic algorithms are useful for global function optimization and NP-hard problems" (De Jong, 1988:121).

In addition, GAs are robust due to the absence of any linearity-type assumptions.. As Holland points out "Moreover, because a genetic algorithm uses a distributed database (the population) to generate new samples, it is all but immune to some of the difficulties-false peaks, discontinuities, high-dimensionality, and so on- that commonly attend complex problems" (Holland, 1986:105). Furthermore, GAs are amenable to parallel implementation to solve problems more quickly.

On the other hand, GAs are criticized due to their problem-independent nature, since problem-specific information can enhance heuristic performance. Another drawback is that GAs do not use memory for responsive exploration. Therefore, GAs may not be seen as clever search procedures. Finally, De Jong points out an important issue in his machine learning research paper: "We have seen that in most cases 500-1000 samples must be taken from the search space before high-quality solutions are found. Clearly, there are many domains in which such a large number of samples is out of the question". He also discusses that the difficulty of choosing a good internal representation for the search space increases with the complexity of the search space. Similarly, one must be careful in providing an effective feedback mechanism (De Jong, 1988:124).

Scatter Search and Path Relinking

Scatter search, uses combinations of reference points to examine a solution space. Tabu search employs path relinking to move between reference solution points. Not

surprisingly, these two heuristic methods are often viewed and presented as a pair (Glover, 2000). These are also methods implemented in OptQuest.

Reeves and Yamada incorporated path relinking in their flowshop sequencing application. Consider two locally optimal solutions to a combinatorial problem such as the n-job, m-machine permutation flowshop sequencing problem. They claim "If the operators we are using induce a big-valley structure, then it is a reasonable hypothesis that a local search that traces a path from one solution to another one will find another, because local optima tend to be found near other local optima" (Reeves and Yamada, 1998:45-61). They further say that even if no better solution is found on such a path, at least some knowledge is gained about the relative size of the basins of attraction to these local optima along one dimension.

Reeves and Yamada developed a specific neighborhood strategy to select certain solutions from a variety of alternatives. Making use of the idea of 'optima linking' in the context of a binary space, a certain path was taken. Among all those that would take the current point one step nearer to the target solution, this was the one traced by finding the best move at each step.

By parameterizing problem data and then generating solutions based on manipulation of the parameters, scatter search applies to many different problems such as neural network training, graph drawing, unconstrained optimization, vehicle routing, multi-objective assignment, and mixed integer programming. As it is in every search procedure, to begin with, we need to create an initial subset of starting solutions. Naturally, better starting solutions will serve in getting better results. To find better starting solutions, we can generate a starting set of solution vectors by heuristic processes

designed for the problem considered (Glover and others, 1999:299).After generating the initial solution, a subset of best vectors is created and labeled as reference solutions. Next, new solutions, which are linear combinations of the reference solutions, are generated. Finally, a subset of the best vectors is used as starting points and the procedure is repeated until a specified number of iterations have been completed.

There are similarities between scatter search and the GA formulation of Holland. Both are population-based approaches, starting with some collection of solutions that evolve according to some guiding process.

However, a major difference between the heuristics lies in combining solutions. GA's crossover is very different than the rounded linear combinations of scatter search, which will be explained next. Furthermore, parent selection also has different implications. Early GAs took the approach of complete randomization whereas scatter search always focuses on good, *elite* solutions (Glover and Kelly, 1995:111-134).

Glover and Kelly claim linear combinations provide a more varied set of possibilities for creating new solutions than GA crossover. They say that linear combinations also avoid the artificiality of resorting to the binary representations as GAs do. To illustrate this point, let us create integer solutions that are combinations of the two solutions $x = 8$ and $x = 14$. Every integer point from minus to plus infinity on the line joining $x = 8$ and $x = 14$ can be generated by rounded linear combinations. However, if we utilize binary representations of length 4, (1 0 0 0) for $x = 8$, and (1 1 1 0) for $x = 14$, then the possible outcomes are more limited. In particular, linear combinations of the binary vectors (1 0 0 0) and (1 1 1 0) yield the schema (1 * * 0) where the '* elements'

can be 0 or 1. Hence instead of producing all possible integer points, these combinations produce only the two vectors (1 0 1 0) and (1 1 0 0), corresponding to x = 10 and x = 12.

Path relinking adds features to scatter search. Linear combinations of the best solutions are regarded as *paths* leading to new solutions. The starting point of the path is the *initiating solution* and the endpoint is called the *guiding solution.* Both of the solutions are known as *reference solutions.* Linear combinations extending beyond the convex region defined by the reference solutions create an *extrapolated relinking* approach.

To serve generating better reference solutions, *multiparent paths* are used. They are created by combining attributes from the set of guiding solutions. In this method, weighted attributes are used to select the better move. The generation of such paths relinks previous solutions that were visited before, in newer and more direct ways. These paths can also be traversed from both start and endpoints simultaneously searching two neighborhoods which means choosing among more alternatives. This approach is called *variation* in path relinking. The assumption of variation is that both small paths will merge at some midpoint. To avoid the danger of bypassing some solutions, crossing the boundary of feasibility is also made possible in path relinking. *Tunneling* allows the search to traverse an infeasible region in order to return to a feasible region. *Strategic Oscillation,* on the other hand, provides a more general means to cross boundaries between feasibility and infeasibility to find critical regions. If these oscillations to recover feasibility are deep, a means of diversification is achieved. Otherwise, intensification is performed to find an optimal solution. Another type of diversification is gained by using constructive neighborhoods for creating new solutions as in the *vocabulary building*

approach. Searching in a constructive neighborhood, incomplete or null solutions converge to the guiding solutions. Vocabulary building combines parts of elite solutions on the path to the endpoint assuming these elite parts will generate good solutions (Glover and others, 1999:297-315).

Tabu Search (TS)

Tabu search is an intelligent search procedure that uses *adaptive memory* to *responsively explore* the solution space of an optimization problem. Glover and Laguna state (Glover and Laguna, 1998:3): "A good analogy is mountain climbing, where the climber must selectively remember key elements of the path traveled (using adaptive memory) and must be able to make strategic choices along the way (using responsive exploration)". A broader and more technical definition is: "Tabu search is a *meta-heuristic* that guides a local heuristic search procedure to explore the solution space beyond local optimality" (Glover and Laguna, 1998:3).

To find a global optimum to a given problem, TS examines possible solutions, or moves, which consist of defining elements called attributes. Example attributes are arcs of a network problem that can be added or dropped to generate moves. Attributes are useful in the neighborhood search of given solutions as mentioned above. In addition, they serve to store solutions efficiently in memory. Rather than storing complete solutions as in the example of *explicit memory structure,* some distinctive attributes of the solutions are stored (*attributive memory structure*). One of the features of explicit memory is that it tracks complete good solutions encountered. These solutions are used to expand the search. In cases where memory space is not a big problem, explicit memory can be used to prevent revisiting previous solutions.

On the other hand, attributive memory stores only the attributes gained from complete solutions via *hash functions*. These functions are used in cycle prevention by means of converting complete solutions to integer values, inexpensively. They are also used in storing complete solutions. If the same hash function values are generated for two different solutions, a *collision* is said to occur. To overcome this problem, a two-level method is used, where colliding solutions are converted to integers one more time.

From a different classification point of view, *short- and long-term memory* types are also used to store the *tabu-status* of attributes beside the types of memories mentioned above. The status of an attribute is *tabu-active* if it is intelligently inhibited from being incorporated to solutions for some reason like creating a solution that is previously visited. Such an attribute is said to be on the *tabu-list,* which is a main feature of adaptive memory structures in tabu search (Fanni and others, 1999:21-32).

The most common type of short-term memory structure in TS is *recency-based* memory, where the memory stores recently changed solution attributes. Here, attributes occurring in solutions recently visited are given a tabu-active status. Solutions, which consist of, or have any of these attributes, are put into the tabu-list. Eliminating these solutions from the current neighborhood prevents revisiting.

Long-term memory is generally *frequency-based.* Here, an array type of memory structure, transition (i), represents an n-dimensional counter, which keeps track of the number of times an attribute (i) is selected to be part of a solution where n is the number of attributes. This gives an opportunity to explore new regions of the solution space according to the frequency with which attributes appear in solutions (Glover and Laguna, 1998:93-122).

Attributes, once labeled tabu-active, remain on the tabu-list for a certain number of moves, which is their *tabu-tenure*. Tabu tenure can also vary for different types or combinations of attributes, which makes the search dynamic and robust. Empirical studies, which are the major information source for TS because of its problem dependent feature, show that effective tabu-tenures also depend on the size of the problem instance. Here are some guidelines to avoid non-effective tenures: Small tenures can be recognized by periodically repeated objective function values. Large tenures miss good solutions.

In TS terminology, to focus in the neighborhood of good solutions is called *intensification* where the neighborhood is generated by the intersection of good attributes. Generally, effective small tenures allow intensifying on solutions close to a local optimum while large tenures can catapult the search to some other region of the solution space when it is stuck in the neighborhood of a local optimum. To make use of this ability is known as *diversification* (Lokketangen and Glover, 1998:624-658). By preventing some moves from being selected for a time period, new regions of the solution space are made available for exploration. Diversification can also be obtained by restarting or modifying the choice rules of moves. Even simple tabu search methods, which most probably have only tabu-tenures as a diversification method, are reported to find good solutions. On the other hand, a TS principle called *proximate optimality principle (pop)* says that good solutions can be found next to good solutions. Thus, a good TS method is the one that effectively combines intensification and diversification.

To repeatedly diversify from the feasible region of the solution space to the infeasible region and vice versa in successive moves introduces the idea of *strategic oscillation*. Here, making changes in evaluation of the solutions to allow infeasible moves

brings changes in neighborhood. This drives the search to cross boundaries between feasibility and infeasibility by a selected depth. Controlled strategic oscillation may drive the search into regions of the search space not otherwise reachable.

Within a TS procedure, there are times one wants to override the tabu-active status of an attribute. A*spiration criterions* facilitate this. The most probable reason to override tabu-active status is that a move involving a tabu-active attribute yields a new best solution. So, in this case, the *improved-best* criterion is used to remove the tabu classification applied to that attribute. Another example is *aspiration-by-default* criterion. Here, if all available moves are on the tabu-list, a move having fewest tabu-active attributes is selected.

Other dimensions of TS memory structures are *quality* and *influence* (Glover and Laguna, 1998:125-148). Quality refers to the ability to differentiate between the amounts of improvement in solutions. TS uses adaptive memory to keep track of attributes that are persistent in many moves (*principle of persistent attractiveness*) or common to good solutions to produce new solutions of high quality. C*andidate lists* are used to store these good solutions in memory. Quality is also obtained by inducing actions that lead to good solutions and penalizing actions that lead to poor solutions (by making use of weights and penalty functions). On the other hand, influence measures the degree of change induced in a solution. It takes the impact of the choices on the quality as well as structure into account that are made during the search. An influential move generally maximizes the changes from the current to the next solution.

There are a variety of ways to terminate a tabu search. A general termination method for TS is to stop if no improvement is detected after a certain number of iterations. Other approaches include total number of iterations or total restarts initiated.

Exploratory Modeling

"Exploratory modeling is a research methodology that uses computational experiments to analyze complex and uncertain systems" (Bankes, 1993:435-449). It can be viewed as a sampling over a very large or infinite collection of models that are plausible given a priori knowledge.

Exploratory modeling is an alternative to the traditional approach where all known information is consolidated into a single model, which is used to make predictions. Taking the amount of uncertainty involved with the real-life problems into account, this consolidative model is nothing but a best-estimate model. Consequently, it is instable, i.e., small input changes cause big changes in some of the outputs in nonmonotonic ways, which brings up questions about the correctness of the model (Brooks, Bennett, and Bankes, 1999:67-80).

Unfortunately, it is too hard to come up with a small valid model with uncertainties using the consolidative approach because the uncertainties make validation very difficult. One may want to build a very detailed model to reduce the amount of uncertainty, but a complex model is not preferred if there are simpler models capable of making sufficiently accurate predictions.

In these cases, a collection of models might be necessary. A simple consolidative model can represent the collection of models only if uncertainties are small, since the

differences among the properties of the plausible models will be similarly small (Bankes, 1993:441). However, for other complex systems involving uncertainty to a great extent, a large sample from the collection must be examined. This examination, called exploratory modeling involves running models drawn from the collection. The selection of which model to run depends on the question to be answered.

A sampling strategy may involve using human judgment to prioritize the investigation of the uncertainties. So, the result of an exploratory analysis will be an image of the collection that improves gradually as more experiments are run. Finally, the analysis provides the most useful results possible based on what is known about the problem (Bankes and Gillogly, 1994:353-360).

In making policy decisions about complex and uncertain problems, exploratory modeling can provide new knowledge even where validated models cannot be constructed. This depends on the fact that partial information can inform policy even when prediction and optimization are not possible.

An application of exploratory analysis is the weapon mix problem (Brooks, Bennett, and Bankes, 1999:67-80). Henning's paper in the field of aerospace (Henning, 1999:36-39) and Droogers and Bouma's paper on soil management (Droogers and Bouma, 1997:1704-1711) are other examples of the use of exploratory analysis.

In general, exploratory analysis allows us to capture the interactions among or within any aspects of analysis, including scenario conditions, decisions, or measures of effectiveness. Furthermore, exploratory analysis looks from the outside in, generating a broad range of outcomes to choose, while a typical sensitivity analysis looks from the inside out, from a single-point solution outward around it (Brooks, Bennett, and Bankes,

1999:67-80). However, exploratory analysis requires a large amount of computational resources. In addition, it does not scale efficiently to multi-scenario situations.

Other Techniques

Another technique to approach the multi-scenario optimization problem is robust optimization. Robust optimization models search for recommendations that are relatively immune to uncertainty in the problem parameters (Bai and others, 1997:895-907). In their research, Bai *et al.*, utilize scenarios to represent uncertainty. These scenarios correspond to possible sets of outcomes giving different objective function values. Then, they combine these values using weights to create the objective function for the robust optimization problem.

Scenario analysis, a recent technique for modeling and optimizing in the presence of uncertainty, employs linear programming to model multi-level nonlinear stochastic events (Gafner, 1997). Laferriere conducted scenario analysis to optimize the mixes of combat systems under uncertainty (Laferriere, 1997). On the other hand, Doran and Brita used scenario analysis to evaluate strategies available to assist the general practitioner in reducing smoking behavior among his patients. They claim that scenario analysis provides a convenient means to simulate the effects of implementing a range of opportunities in isolation or in combination. They further report: "By defining 'scenario' in which a number of variables are varied simultaneously, the methodology allows the exploration of complex processes on various assumptions" (Doran and Brita, 1998:1013).

Another technique is stochastic modeling, which is mathematical modeling under uncertainty. Any mathematical model where one or more of the coefficients are not fully

known at the time of decision making, is a stochastic model. Newton and Guttorp presented a statistical analysis providing a stochastic model of early hematopoiesis, production of blood cells (Newton and Guttorp, 1995:1146).

Hill and McIntyre claim that these optimization methods appear limited to multiple realizations of a single planning scenario; however they see them as powerful techniques for examining uncertainty within a planning scenario. They define a robust force structure as that force structure "providing the best overall outcome as evaluated with respect to some set of scenarios each of which has an associated likelihood of occurrence (Hill and McIntyre, 2000:28).

Extending these works to come up with a search method for robust multi-scenario space as opposed to working in particular scenario projections of exploratory analysis, we utilize a 'parts make the whole' view in that subspaces generate the multi-scenario space according to the likelihood of occurrence. Then, we use scatter search to find a good air force structure in the composite multi-scenario space.

CFAM

The Combat Forces Assessment Model (CFAM) currently used by the United States Air Force, examines force structuring options for a given scenario. This model expands capabilities available in its predecessors Heavy Attack, Theater Attack Model (TAM), and Mixmaster.

Heavy Attack assigned values to each target and optimized the total target value destroyed (TVD), which was nonlinear. It did not contain budget constraints and did not model aircraft attrition. Heavy Attack was the most aggregated of the three models

mentioned above, allocating sorties to targets without directly modeling weapons. On the other hand, Heavy Attack determined the best weapon and computed effectiveness for a sortie.

TAM was a highly detailed model offering multiple linear objective functions and budget and attrition constraints. It optimized globally across time, which made the runtime very large. Unlike Heavy Attack, TAM assumed perfect weather knowledge. The model objectives required the user to specify goal achievement at a particular time.

Mixmaster was a hybrid model. The model used a linear program with TVD objective function and a greedy sortie allocation scheme.

Generally, conventional munitions optimization models try to determine the effect of having or not having a particular weapon in the inventory (*tradeoffs*), the best way to allocate munitions and aircraft to targets, given a fixed inventory and scenario (*allocation*), and type of weapons needed to meet goals for a given scenario (*requirements*) (Yost, 1996:53-71). The models with TVD objective functions need the user to specify the desired campaign to be conducted. This means providing the kill sequence for the targets while minimizing attrition and resource expenditure. This means the view of the user is entered as input to the model.

To overcome these problems, CFAM provides a choice among objectives. The three objectives common to all the models above are maximizing total target value destroyed (TVD), minimizing aircraft attrition, and minimizing cost of buying new aircraft and weapons. CFAM additionally provides two more objectives: (1) minimizing the sum of the penalties associated with not achieving the goals, and (2) minimizing the time required to accomplish the phases. The first provides feasibility to the model if the

time objectives are not met while the second allows a user definition of overlapping between phases. In other words, a phase can start before all the goals in the previous phase are met. As stated above, CFAM answers questions about how to employ air assets such as the aircraft sorties and equipment needed to destroy specified targets, the time needed to reach campaign goals, and aircraft attrition.

III. Comparison of GA to Scatter Search

Introduction

In this chapter, the genetic algorithm meta-heuristic approach of Bennett is compared to our scatter search meta-heuristic. The OptQuest package is used to facilitate our approach. To make a comparison, we conducted a 249-run test experiment using OptQuest. Our test results provided the basis for continuing the use of OptQuest. The following GA discussion and GA results are from Bennett's study and are reproduced here for completeness. See Bennett's thesis (Bennett, 2000:41-47) for details.

Genetic Algorithm Meta-Heuristic

The Experiment

Each candidate force structure involved five different types of aircraft. The maximum number of any strike aircraft included in a candidate force structure was limited to 63. The GA employed was the GENEtic Search Implementation System (GENESIS Version 5.0) written by John Grefenstette (Grefenstette, 1990:3). Using a randomly generated initial population, CFAM was used to evaluate each candidate force structure.

GA Performance Analysis

Bennett evaluated 942 force structures in three 12-generation GENESIS experiments. His 15 best force structures found are shown in Table 1. Note, the GA

heavily favored Aircraft 4 and Aircraft 5 while barely utilizing Aircraft 3. A practical force structure may require a more balanced force.

Table 1. Top 15 Force Structures Found By Bennett

		Number of Aircraft by Type					Fitness Values			
Rank	Trial	Acft 1	Acft 2	Acft 3	Acft 4	Acft 5	Scenario1	Scenario2	Scenario3	Total
1	181	15	4	0	56	53	3708.50	3662.50	3672.00	3681.00
2	869	18	2	5	42	63	3610.50	3565.00	3577.00	3584.17
3	258	9	18	1	55	47	3589.50	3559.00	3575.00	3574.50
4	250	24	4	0	55	47	3593.00	3558.00	3571.00	3574.00
5	214	9	15	1	58	47	3591.50	3561.00	3565.50	3572.67
6	855	16	7	5	42	61	3557.50	3517.50	3534.50	3536.50
7	241	16	4	0	56	55	3560.00	3516.00	3530.50	3535.50
8	288	21	4	1	56	49	3549.00	3510.00	3524.00	3527.67
9	896	16	15	4	36	60	3543.00	3508.50	3526.00	3525.83
10	230	24	4	1	55	47	3542.50	3508.00	3526.00	3525.50
11	232	9	19	1	55	47	3542.50	3508.50	3524.50	3525.17
12	884	16	7	4	45	60	3509.00	3466.50	3520.00	3498.50
13	863	16	7	4	45	61	3461.00	3417.00	3471.00	3449.67
14	900	16	7	5	44	61	3459.50	3417.00	3470.50	3449.00
15	872	31	2	5	44	51	3431.00	3402.00	3459.50	3430.83

The GA did not find very balanced solutions despite the apparently complementary results across each solution. This is likely a result of poor solution space coverage in the initial population, along with a low mutation rate and a small number of evaluations. Figure 2 plots the initial solutions. Careful observation shows that this population is not particularly diverse.

Three typical GA measures of performance are on-line, off-line, and best so far. The data are provided in Table 2 and plotted in Figure 3 for Bennett's GA Experiment 1.

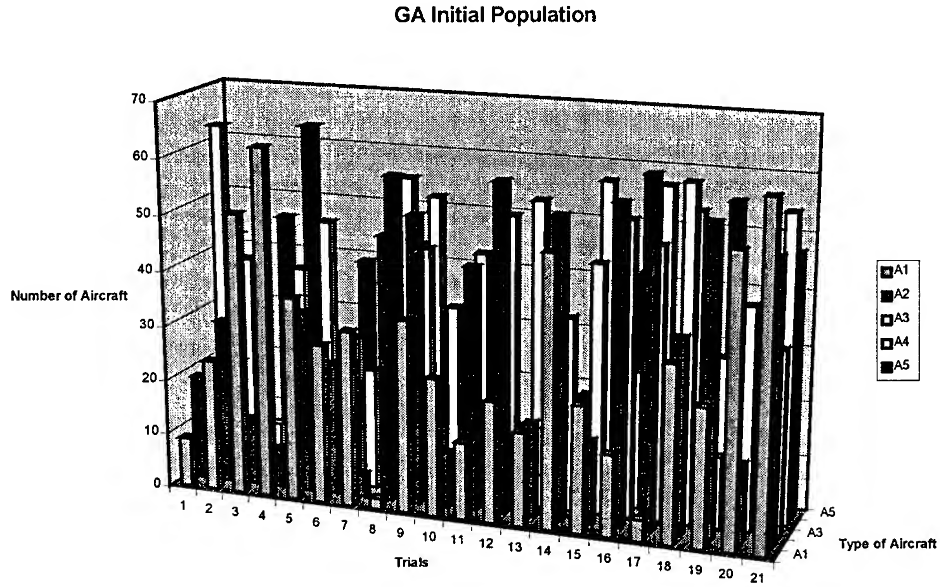


Figure 2. GA Initial Population Coverage of Solution Space

On-line performance is the average of all evaluations. Off-line performance is the average of the current best solutions. The best so far is the overall best solution found. We used the measure best so far to compare the two heuristics.

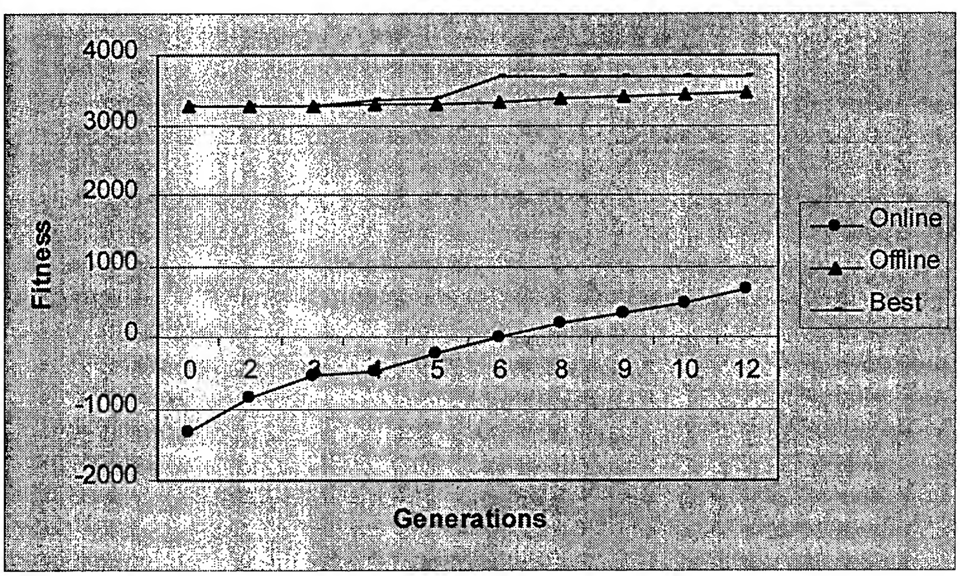


Figure 3. GA Performance for Bennett's Experiment 1

All three of Bennett's experiments gave similar results. Performance figures showed the best-so-far curve leveling off while on-line performance curves were still increasing. It is our belief that the GA got "stuck" in a local optimum region and could not escape.

Table 2. GA Performance Data for Bennett's Experiment 1

Experiment 1								
Generation	Trials	Lost	Conv	Bias	Online	Offline	Best	Average
0	30	0	0	0.551	-1331	3278	3278	-1331
2	76	0	0	0.611	-840	3278	3278	-106
3	103	0	0	0.639	-541	3278	3278	323
4	131	0	0	0.64	-468	3295	3358	-53
5	155	0	1	0.671	-225	3307	3371	852
6	182	1	1	0.694	-9	3319	3681	1229
8	227	2	2	0.716	187	3391	3681	1481
9	249	2	2	0.721	340	3417	3681	1966
10	270	2	3	0.718	469	3437	3681	2047
12	315	3	4	0.746	689	3472	3681	2136

Scatter Search Meta-Heuristic

Solution Structure

Similarly, we also used a candidate force structure consisting of five different types of aircraft for ease of comparison to the GA meta-heuristic. For comparison with the GA approach, the maximum number of any strike aircraft included in a force structure aircraft type is again limited to 63. A sample solution to the problem would be represented as follows:

$$\begin{array}{llllll} V_1 = (& 2 & 0 & 16 & 8 & 10). \\ & A_1 & A_2 & A_3 & A_4 & A_5 \end{array}$$

V_1 is a force structure consisting of A_1 = two type-one aircraft, A_2 = zero type-two aircraft, A_3 = 16 type-three aircraft, A_4 = eight type-four aircraft, and A_5 = ten type-five aircraft.

Evaluation

The particulars of the Scatter Search are embedded in the algorithm, OptQuest CL prepared by Laguna (OptQuest Callable Library for C Applications, Optimization Technologies, Inc). Similar to GENESIS, this algorithm allows a user to build an application to search for the optimal solution to his problem using the "black-box" approach to evaluating the objective function. The application uses the objective function evaluator, CFAM, to measure the quality of the candidate solutions generated by the OptQuest CL routines.

An important feature of OptQuest CL is that it uses the variable ranges and the constraints to determine the feasibility of the solution before the solution is sent to the objective function evaluator, CFAM. The OCLSetBoundFreq function sets the frequency parameter for the boundary search strategy. The boundary search strategy is a mechanism to direct the search towards the feasibility boundary defined by the bounds on the decision variables. The default value is 0.5, which means that the strategy to drive the values of the decision variables towards the boundary is used 50% of the time when new solutions are generated. If good solutions are likely to fall at or near the feasibility boundary, it is recommended to increase the value of this parameter. Conversely, if good solutions are suspected to lie near the middle of the variable range (when no constraints are defined), it is recommended to decrease the default value for the boundary strategy. After running 400 experiments shown in Appendix 2, we decided to use 0.3 as the boundary strategy, which gave the highest objective function value and a good average.

Sactter Search Performance Analysis

A total of 249 force structures were evaluated. Using the same performance measures from Genetic Algorithms and counting 20-run blocks as generations, we found very good results, which are more than two times better than the GA results. This is a probable consequence of OptQuest's ability to intelligently sample the solution space during initialization. Figure 4 can be compared to Figure 2. The OptQuest initial solutions seem to offer greater diversity than the GA initial solutions. While the GA generates random initial candidate structures, OptQuest employs a systematically defined initial population.

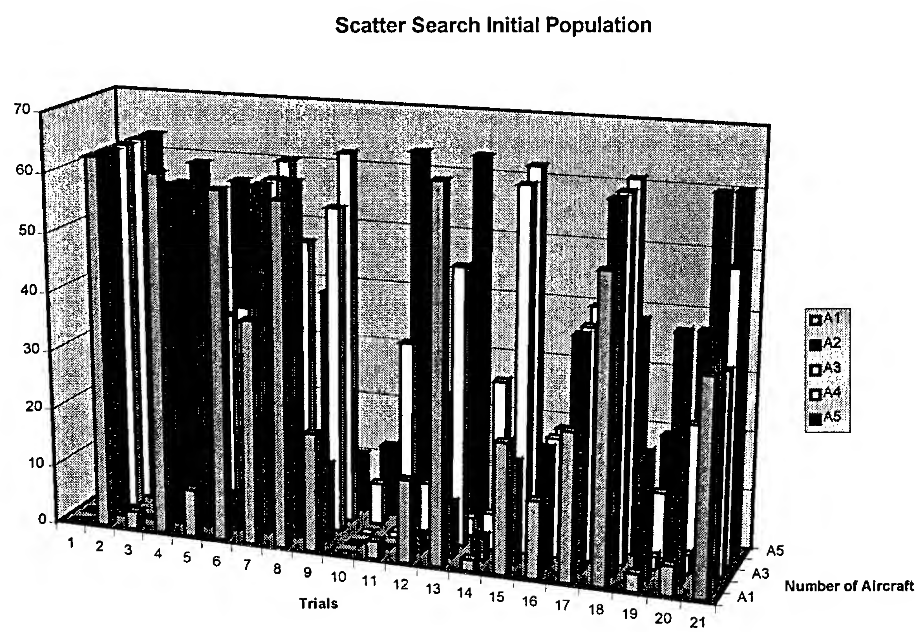


Figure 4. Scatter Search Initial Population Coverage of Solution Space

Unlike the GA, Scatter Search favors Aircraft 4 and Aircraft 5 only slightly. The best force structure, trial 22, which consists mainly of the first 3 types of aircraft,

supports this idea, as seen in Table 3. More balanced structures, such as trials 239 and 149, also have high objective function values. Furthermore, Scatter Search utilizes Aircraft 3 better, as opposed to GA's poor utilization.

Table 3. Top 15 Force Structures Found By OptQuest

		Aircraft		Number	by	Type	Fitness Values			Average
Rank	Trial	A1	A2	A3	A4	A5	Scenario1	Scenario2	Scenario3	Fitness
1	22	11	10	13	1	0	8253.5	8323	8364.5	8313.667
2	14	2	4	6	27	1	8044.5	8034	8087.5	8055.333
3	196	3	6	5	26	9	7589.5	7564.5	7626	7593.333
4	53	0	0	0	9	55	6868.5	6837	6890	6865.167
5	237	0	0	0	2	4	9720.5	-300.5	9752.5	6390.833
6	194	1	1	2	9	0	-702.5	9322	9343.5	5987.667
7	140	4	31	3	17	28	5934.5	5918	5964	5938.833
8	248	0	7	1	5	3	-780.5	9266.5	9321.5	5935.833
9	43	5	6	1	27	47	5779.5	5733.5	5790.5	5767.833
10	10	0	0	0	7	12	9045	-976.5	9078	5715.5
11	239	1	4	3	5	7	-1008	8989	9010.5	5663.833
12	149	17	24	18	17	17	5423	5371	5460.5	5418.167
13	200	1	3	4	19	4	-1596	8426	8442.5	5090.833
14	11	3	0	1	32	63	5078	5034.5	5057	5056.5
15	245	7	1	4	6	18	-1996	8244.5	8298.5	4849

Best-so-far and on-line curves are not generally available via OptQuest but were derived from the data for comparison purposes.

Table 4 and Figure 5 shows the best-so-far curve leveling off. However, the on-line performance curve is still increasing, as it was in GA approach. This warrants further investigation. Many more runs are required before coming to any firm conclusions.

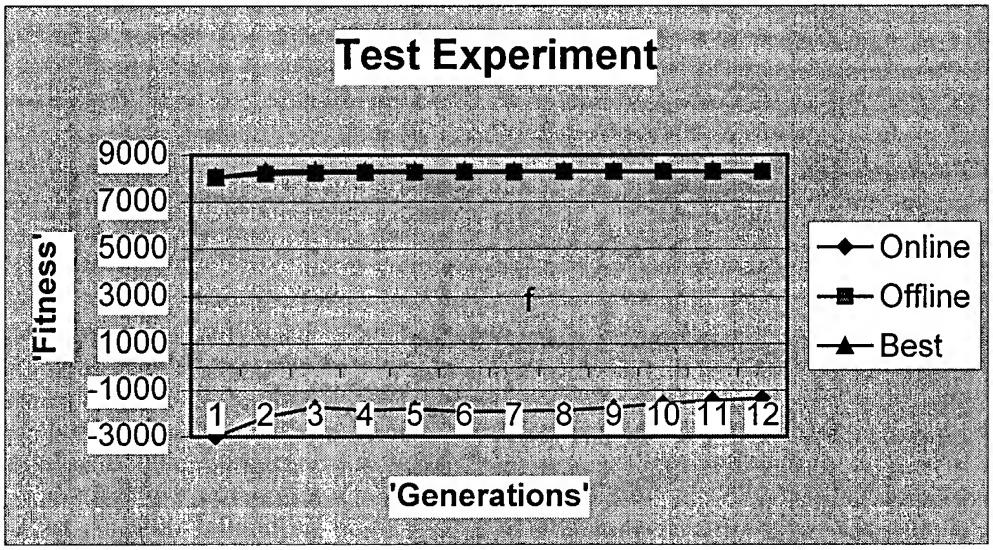


Figure 5. Scatter Search Performance for Test Experiment

Results

Both the GA and OptQuest employ a population-based heuristic available in software amenable to our multi-scenario optimization problem. Because our 'black-box' function evaluator uses CFAM, each evaluation is computationally expensive. Because of this computational expense, we want our optimizing meta-heuristic to make use of the functional evaluations.

The test results favor OptQuest over the GA. The OptQuest results show higher total fitness values and greater diversity among the solution values. Further, these early OptQuest solutions appear more balanced than the early GA solutions with respect to usage of each aircraft type.

The test results also point out a potential problem with the total fitness function. While the fitness values for the GA solutions do not seem to vary much by scenario, this is not the case for OptQuest solutions. Clearly, a truly robust solution must be adequate in

every scenario in addition to best overall. Further, the fitness function appears to contain some bias favoring excludingly small force structures. Clearly, reality necessitates larger force structures than trial 237 in Table 3 might suggest.

The next chapter formally presents the scatter search methodology.

Table 4. Scatter Search Performance Data

		Fitness Values			
Generation	**Trials**	**Online**	**Offline**	**Best**	**Average**
1	21	-2993.81	8055.333	8055.333	-2447.9
2	42	-2143.31	8184.5	8313.667	-1153.02
3	63	-1718.64	8227.556	8313.667	-1101.29
4	84	-1841.26	8249.083	8313.667	-2385.57
5	105	-1786.97	8262	8313.667	-1655.94
6	126	-1910.79	8270.611	8313.667	-2845.02
7	147	-1887.14	8276.762	8313.667	-1292.4
8	168	-1865.86	8281.375	8313.667	-1618.65
9	189	-1733.33	8284.963	8313.667	-643.595
10	210	-1558.45	8287.833	8313.667	29.56349
11	230	-1438.93	8290.182	8313.667	-406.968
12	250	-1336.6	8292.139	8313.667	-828.5

IV. Methodology and Sensitivity Analysis

Introduction

In this chapter, we focus first on the methodology of employing an advanced meta-heuristic search procedure, *i.e.* Scatter Search, to guide the use of the existing Air Force Studies and Analyses Agency's (AFSAA) combat model CFAM to evaluate the effectiveness of candidate force structures across the multi-scenario space and terminating with robust solutions of AEF strike force structures. We then focus on analyzing the results of our experiment.

Methodology

Our approach is based on Hill and McIntyre's methodology for robust, multi-scenario optimization (Hill and McIntyre, 2000:27). Defining *robust force structure* as a "force structure providing the best overall outcome as evaluated with respect to some set of scenarios each of which has an associated likelihood of occurrence", they suggest using a controller interface to perform necessary interactions between the meta-heuristic and the combat model. The controller provides the model (CFAM) with candidate solutions generated by the meta-heuristic. CFAM evaluates these solutions. The controller takes the evaluations, or measures of effectiveness (MOE), combines different scenario MOEs for a specific force structure into a single measure of merit (MOM), *i.e.* a weighted objective function value, and provides them to the meta-heuristic to continue the search of

unexplored solution space regions. The cycle stops after a specified number of iterations or when convergence to an optimum is detected.

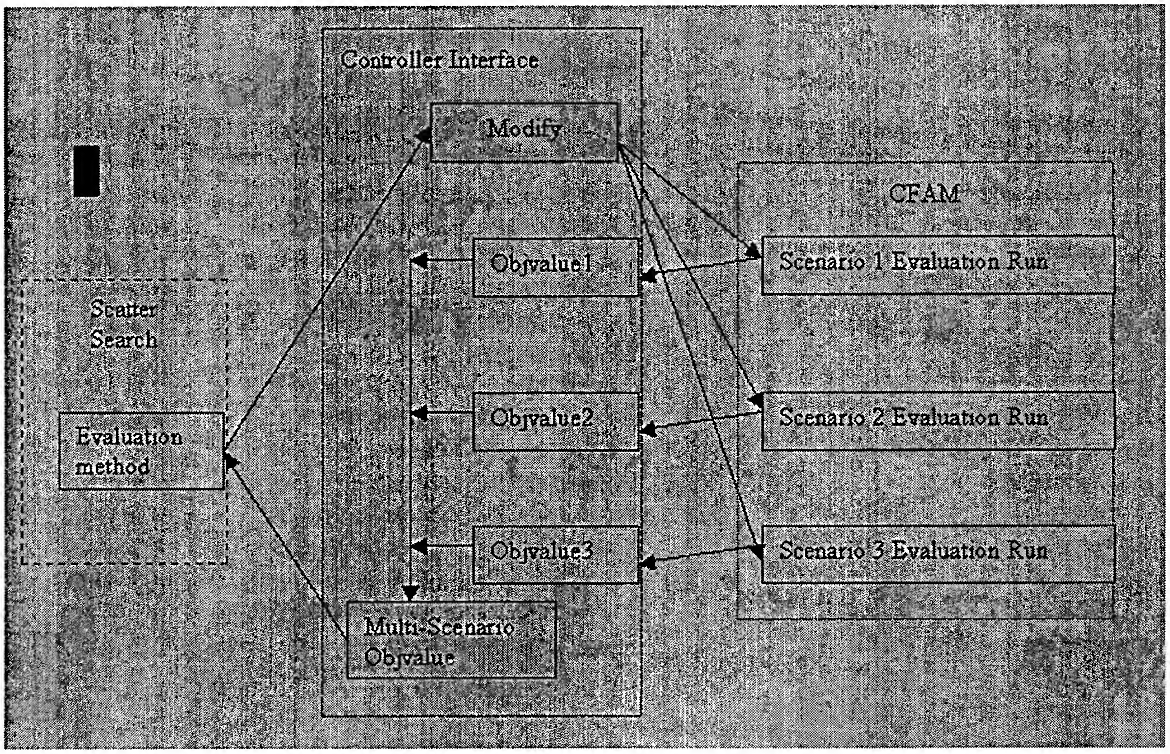


Figure 6. Robust Multi-Scenario Optimization Methodology

The methodology specifics applied to our problem are as follows (Figure 6): The controller interface is a combination Visual Basic/DOS routine playing the role of a data manager. The employed heuristic method is a Scatter Search Algorithm, which guides the search examine different force structures. CFAM is our combat model used to evaluate the force structures suggested by the Scatter Search.

The controller serves four functions. First, the controller routine makes necessary changes in the CFAM input files to accommodate the force structure provided by the Scatter Search. Second, it runs CFAM for the input force structure. Then it combines

CFAM results into the weighted objective function value. Finally, it triggers the Scatter Search again with this value.

Scatter Search Meta-Heuristic

As discussed in the previous chapter, due to the computational expense of the objective function evaluations, we preferred a search method that determined the feasibility of the solutions before they are sent to the evaluator, CFAM. In addition, our test results showed that Scatter Search gave better and more balanced force structures.

Scatter Search generates and places the candidate solutions into a text file. The file is read by the controller interface which makes the necessary changes in the CFAM input files, runs CFAM for each scenario, combines these outputs (each scenario) into a single objective function value and passes this value to OptQuest via a test file.

Combat Forces Assessment Model (CFAM)

CFAM is currently used by United States Air Force for evaluating force structuring options for a given scenario. CFAM is a large-scale linear program (LP) used as an analytical tool for determining the impacts of budget, attrition, force structure, targeting decisions, and munitions inventories on war fighting capabilities (AFSAA, 1997:3).

CFAM produces its outputs, whenever the campaign to meet a scenario objective completes or seven time periods have elapsed. Five of the standard CFAM outputs are used to produce Bennett's MOE to evaluate the force structures (Bennett, 2000:39). The MOE is a weighted objective function, which we used for ease of comparison. The weights assigned to each output are based on opinion. The five CFAM outputs used are: final phase of campaign encountered, remaining targets in the current campaign phase, campaign

completion, the time period when the scenario was complete, and total number of aircraft lost. These combine to produce an objective value for each scenario. Similar weights are used to combine the objective function values from each scenario to construct Bennett's multi-scenario objective function designed to find robust force structures. The campaign phases are: 1) SEAD (suppression of enemy air defense), 2) HALT (halting enemy advancement), 3) ATTRIT (attrition of enemy forces), and 4) the counter offensive.

CFAM comes in two variants. Quick Strike allows the user to optimize within distinct time periods of an air campaign, while Time Strike optimizes across an entire campaign (AFSAA, 1997:4). We used Quick Strike to find the parameters needed to calculate the multi-scenario objective function value of a candidate solution.

The methodology is applied against Bennett's three notional scenarios derived from the unclassified CFAM training database. The weapons inventory remained constant in the 7-day-long scenarios, which differed slightly in favoring ground targets to air assets. Our focus was on the allocation of five types of aircraft, again derived from Bennett's database by enhancing the distinctions in surge rate, minimum altitude limit, and minimum estimated kills per sortie. The parameters of baseline aircraft are shown in Table 5. Bennett's CFAM setup is given in Appendix 8. For more detailed information see Bennett (2000).

The Controller Interface

All the interactions between CFAM and OptQuest are done through a batch file called *master.bat* (Appendix 7). This file, written originally by Bennett, is used here for the comparison of two heuristic search methods, Genetic Algorithms and Scatter Search. The file is called from the user-written evaluation method of OptQuest (Appendix 1), where it

receives the candidate force structure and returns the evaluation after executing CFAM once for each scenario and combining the results into the single weighted objective function value.

Table 5. Bennett's Candidate Aircraft Types and Characteristics

ID	Description	Sortie Surge Rate	Min Alt (ft)	Min EKS
1	Aircraft 1	2	9999	0.005
2	Aircraft 2	2	9999	0.005
3	Aircraft 3	2	9999	0.005
4	Aircraft 4	2	9999	0.005
5	Aircraft 5	2	9999	0.005
6	Aircraft 6	2	9999	0.005
7	Aircraft 7	2	9999	0.005
8	Aircraft 8	2.5	1000	0.02
9	Aircraft 9	2.4	600	0.05
10	Aircraft 10	1.6	600	0.04
11	Aircraft 11	2	9999	0.005
12	Aircraft 12	2	9999	0.005
13	Aircraft 13	2	9999	0.005
14	Aircraft 14	2	9999	0.005
15	Aircraft 15	2	9999	0.005
16	Aircraft 16	2	9999	0.005
17	Aircraft 17	2	9999	0.005
18	Aircraft 18	0.3	9999	0.005
19	Aircraft 19	2	600	0.01

Within the body of the controller interface, user defined weights and CFAM output parameters enable us to calculate a value for our scenario objective function, which is the same as Bennett's (Bennett, 2000:39):

$$O_i = -w_{1_i} D_0 + w_{2_i} D_1 + w_{3_i} D_2 - w_{4_i} D_3 - w_{5_i} D_4 - w_{6_i} Atotal \quad (1)$$

where

w_{1_i} through w_{6_i} are parameter weights defined by the decision maker

D_0 = time period when campaign ended (ranging from 1 to 7),

D_1 =campaign completed (0 for no, 1 for yes),

D_2 = current phase when campaign ended (ranging from 1 to 4),

D_3 = total aircraft lost,

D_4 = targets remaining for current phase,

Atotal = the total number of aircraft in the force structure.

Bennett used equal parameter weights for each scenario and put importance on completing the campaign, as well as any campaign phase. He penalized big force structures, long campaign completion times, large amounts of aircraft losses and large numbers of remaining targets. We discuss some of the drawbacks of this set up in the sensitivity analysis section. Bennett further calculated the multi-scenario objective function value for force structure v_j as:

$$v_j = \sum_{i=1}^{i} P_i O_i \tag{2}$$

where i is the scenario number, j is the number of the candidate force structure, and P_i is the probability of scenario i occurring. The parameter weights and probability of occurrence defined by Bennett and used here are:

$w_{1_i} = 50, w_{2_i} = 10000, w_{3_i} = 125, w_{4_i} = 50, w_{5_i} = 50, w_{6_i} = 50,$ and $P_i = 1/3$ for $i = 1, 2, 3$

(Bennett, 2000:40).

Sensitivity Analysis

The experiments were run on a notebook computer with 256 megabytes of random access memory running under Windows 98 with a 366 MHz Pentium II processor. The

notional scenarios were constructed using CFAM version 2.5 and evaluated using GAMS 2.5 linked with the CPLEX Linear Optimizer version 6.5.2. The Scatter Search guiding the search procedure was OptQuest version March 3, 2000, compiled using Microsoft Visual C 6.0.

A total of 689 force structures were evaluated in a single OptQuest experiment. The data obtained from these 689 solutions can be found in Appendix 4. For ease of comparison to Bennett, the best 15 force structures found are extracted from this list and shown in Table 6. Unlike the GA results, structures found by OptQuest seem to cover a larger portion of the solution space. We conjecture that the GA with its similar structures was stuck in a local optimum due to an ineffective initial population. OptQuest, however, screening out the solutions that are likely to be poor without even sending to the CFAM, does eliminate the problems facing GA concerning solution space coverage. This idea is supported by the great diversity in the solutions table, compared to GA's best solutions table in the previous chapter.

Table 6. Best 15 Solutions Found by 689-run Experiment

Rank	Trials	Aircraft A1	Number A2	A3	by A4	Type A5	Fitness Values Scenario1	Scenario2	Scenario3	Total Fitness
1	226	10	0	0	5	0	9333.5	9321.5	9371.5	9342.167
2	462	7	8	7	8	0	8576.5	8530	8576.5	8561
3	447	10	1	2	8	15	8270.5	8231	8284.5	8262
4	249	7	10	10	10	2	8100	8070	8112.5	8094.167
5	14	2	4	6	27	1	8044.5	8034	8087.5	8055.333
6	651	10	16	16	12	3	7211	7163.5	7255	7209.833
7	679	0	0	52	5	1	7145.5	7120.5	7181.5	7149.167
8	680	0	0	63	0	0	6933.5	6917.5	6968	6939.667
9	685	4	5	51	3	0	6911	6868	6954	6911
10	53	0	0	0	9	55	6890.5	6842	6895	6875.833
11	54	26	4	11	9	15	6796	6781.5	6834	6803.833
12	327	3	1	1	0	0	-339	9718.5	9739	6372.833
13	406	4	0	2	0	0	-369	9670	9691	6330.667
14	372	3	1	4	0	0	-485	9567.5	9587.5	6223.333
15	373	2	8	24	26	17	6219.5	6184.5	6223.5	6209.167

Bennett's concern about lowest level of organic maintenance support for aircraft, *i.e.* squadron level, also arises in our situation. Taking into account that a fighter squadron usually consists of 18 or 24 aircraft, employing a portion of a squadron clearly is not the right decision because of the rising cost. To avoid this problem, more realistic force structures can be selected from the best solutions table. This flexibility in meeting different needs is provided by the robustness of our approach.

On the other hand, another concern not applicable to GA results has emerged, as test results also pointed out earlier. The objective function tolerates unrealistically small structures, as seen in trials 327, 406 and 372, having at most just 8 aircraft in the force structure. The penalty applied to parameter *Atotal* for finding smaller force structures should be revised. In addition, the function should also avoid assigning high values to force structures, which have obtained a low value in one of the scenario evaluations. The above

trials, 327, 372 and 406, also provide examples for this case. The decision maker clearly would not employ an expeditionary force that meets the objectives of two scenarios, but completely fails in one of the probable crisis situations it would face.

Another indication of the test results was that Scatter Search did not favor any one of the 5 types of the aircraft, while Bennett's GA heavily favored Aircraft 4 and Aircraft 5. It also used a balanced selection method of the aircraft. His GA barely utilized Aircraft 3. For multi-scenario optimization problems, the superiority of Scatter Search to GA is verified by the 689-run experiment.

To find robust force structures to our multi-scenario optimization problem, we used an approach similar to Bai, *et al* (Bai and others, 1997:898). By introducing weights and combining them, we generated a multi-scenario objective function value across the range of uncertainty represented by the scenarios.

Exploratory analysis approach is also applicable to our problem. To relieve the concern about employing a portion of a squadron, we have the option to select the more suitable force structure among the best solutions found in order to meet our needs.

To meet the definition of robustness introduced by Ignizio, we need to find force structures whose objective function values are relatively immune to the slight changes in the original structure (Ignizio, 1999:6). In order to do this, we performed a regression analysis using JMP IN Statistical Discovery Software Versions 3.0 and 4.0. The details of the analysis are given in Appendix 5. We fitted a regression function to our experiment data and searched the solution space for robust regions with the guidance of this function. To perform the search, we examined the neighborhood of the stationary points of the fitted function. However, the data was so spread out that fitting a regression function was

smoothing all the variability in the data and specifying the local optima as outliers. The approach was likely to bring robustness but its necessitation of sacrificing optimality made us look for alternative ways to find an answer to the robust multi-scenario optimization problem. We also regressed over only the local optima, and were able to find a stationary point for Aircraft 3, but the function was not robust in the neighborhood.

An alternative approach was looking at the plot of the experiment results in the solution space through a hyperplane defined by any two of the aircraft. To obtain a clear picture of the hyperplane, we averaged the data points over the number of aircraft (Figure 7). These figures show that it is still hard to find a relatively smooth region providing robust solutions because of the rugged nature of the solution space.

For further examination, we used the average objective function value by type of aircraft table (Appendix 6), which provided the basis for Figure 7. The relevant portion of

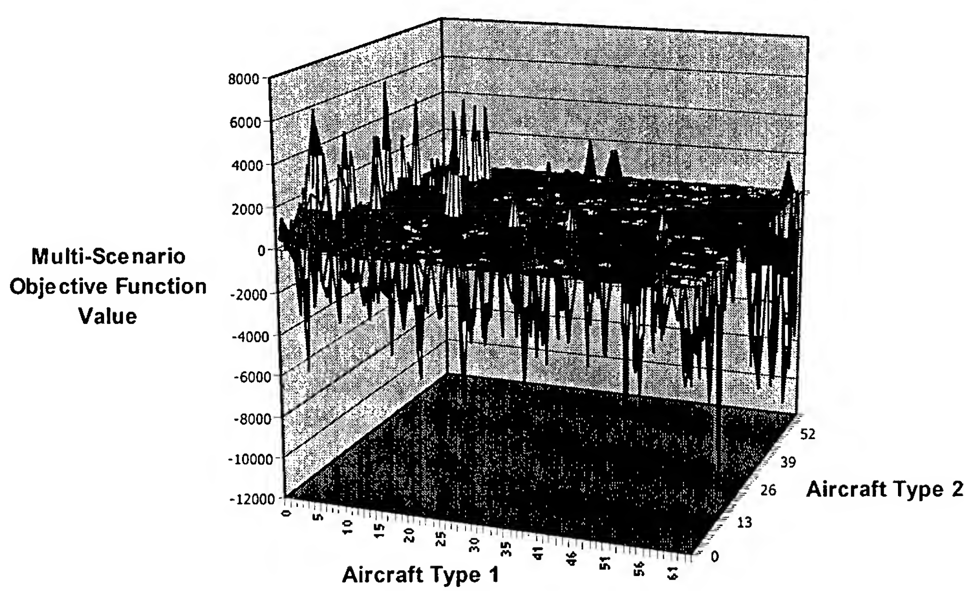


Figure 7. Average Objective Value of Aircraft 1 vs. Aircraft 2

this table is given in Table 7. The results supported our regression analysis: The robust air expeditionary force should be constructed in the neighborhood of 7 Aircraft Type 4, which is the exact same result obtained by the regression approach. The force structure should also have 7 Aircraft Type 1, in the neighborhood of the regression result of 5 aircraft.

Table 7. Relevant Portion of the Objective Value Average Table

Number of	Type of Aircraft				
Aircraft	A1	A2	A3	A4	A5
0	-32.11742424	**595.6432**	**127.8956386**	-602.596	**212.3323**
1	-620.5530303	**805.3023**	**974.8809524**	-2176.33	**531.1296**
2	-62.88571429	**1092.8**	**-121.4733333**	-1326.79	**-245.548**
3	38.72727273	-457.8	**174.9416667**	-374.471	**32.17778**
4	-371.6621622	205.9097	-97.58928571	-775.897	735.25
5	-220.2356322	508.4386	-752.6018519	**1073.56**	-2034.32
6	**-127.3133333**	-367.765	-130.5238095	**52.4023**	-1804.62
7	**191.5944444**	-1414.72	619.1875	**557.0625**	-4146
8	**-273.3733333**	-156.167	-544.7651515	**629.7105**	-2462.23
9	-549.3431373	-192.833	-581.8181818	-520.005	-4707.53
10	388.7971014	365.625	-358.8452381	570.1739	-3346.88
11	948.7111111	-1055.29	-528.1666667	-1033.01	-3167.42
12	-2512	492.8333	-1360.833333	793.75	-3171.47
13	-290.2708333	-1944.92	-132.8333333	-1038.55	-3821.13
14	-367.6212121	-992.667	134.5606061	-1732.01	-5578.44
15	142.1833333	-1941.6	-155.5333333	-775.083	4414.556
16	-660.6060606	591.0714	-176.0625	-1417.89	-2543.08
17	-34.375	-1178.35	-4926.619048	-911.716	-255.444
18	-368.3181818	-2566.22	-2837.916667	1507.808	-1231.88
19	-1475.65	-1143.3	-2002.333333	-2136.88	-1681.88
20	-362.1041667	-926.375	-2286.125	317.9444	-2302.28
21	-521.9761905	98.84848	-1198.515152	-1841.1	-1789.98
22	-2375.384615	-536.806	-2586.666667	-5.52083	-3593.89
23	-3204.083333	-1941.14	-1707.5	-1512.31	303.7667
24	-1023.583333	651.1458	1171.458333	1237.389	-8055.17
25	-2862.766667	-2405.61	-601.6666667	1266.028	-2434.58
26	-1796.962963	-933.796	-1600.333333	-388.296	-2577.2
27	-925.7	-2525.25	-1116.638889	38.95833	-1213.08
28	-5230.958333	-1414.03	505.1666667	-120.5	-1670.75
29	-3203.066667	1895.083	2321.25	-663.7	-1824.08
30	-1238.916667	118.75	330.25	-1857.87	-2319.57
31	-342.9166667	-374.867	-2661.916667	-200.667	-767.3
32	-1996.722222	-2762.42	-3557.681818	-1366.32	-3335.61

These results are also verified by the best solutions table having 8 and 9 Aircraft Type 4, in 4 out of 15 structures; 7 and 10 Aircraft Type 1, in 5 out of 15 structures (Table 6). The analysis further points out that we should have around 1 Aircraft Type 2 (0 and 1, in 8 out of 15 also in Table 6).

There is an indication of robustness in regions where Aircraft Type 3 is utilized at levels of 0-3 and 28-30 aircraft. However, this area is smoothed in our local optima regression, which favored 18 aircraft. Finally, Aircraft Type 5 has relatively stable values in the range 0-4 as verified by the best solutions table 11 times.

V. Findings and Conclusions

Findings

As widely discussed in the previous chapters, the use of Scatter Search meta-heuristic to guide the quest for optimality in the non-convex solution space of our multi-scenario optimization problem has performed dramatically better than the use of Genetic Algorithms (as seen by the great difference in results obtained). Integrating simulation and optimization, and employing a neural accelerator to screen out solutions of probable poor quality, OptQuest has proved to be a powerful tool to examine solution spaces of a huge and complex nature.

The robust optimization technique of incorporating uncertainty into a weighted objective function and the exploratory analysis approach of providing near optimal solutions to the decision maker to trade off in deference to other factors, melded a successful research methodology. This methodology also gives the flexibility of changing the problem setup to meet different needs and concerns, which can be performed in two ways: (1) Changing CFAM inputs, (2) Changing the weights of the associated parameters in the scenario objective function. In our study for example, the weight for parameter *Atotal* should be changed to avoid favoring exclusively small air expeditionary force structures. CFAM also presents a variety of options. In addition, the range of the available number of aircraft can also be changed in the evaluation method.

We have obtained good results using CFAM, the latest combat model to build force structures to respond to a single theater scenario, as the evaluator in our study.

However, CFAM also fits in the category of models whose runs are computationally expensive. The processing times will become even longer when the methodology is applied to real scenarios, which will most probably try to allocate more than five types of aircraft.

Conclusions and Areas for Further Research

Our analysis showed that the multi-scenario objective function developed by Bennett (Bennett, 2000:40) needs to be revised. As mentioned in the previous chapter, the current objective function allows exclusively small force structures to find a place among the best solutions. Under normal conditions, there will not be a pilot in the world who would want to be a part of an air expeditionary force structure consisting of only 5 aircraft as trial 327 in Table 6 suggests. Besides, the current function assigns a high value to the force structures performing well in responding to two of the scenarios but fairly bad in responding to the other one. Another drawback of the function is that it gives a very rugged solution space full of local optima, leaving very little space for robust plateaus if any at all. Clearly, the definition of 'robust' is about having values that occupy some relatively flat space, or *plateau,* across changing input parameters.

Our methodology performed well with respect to notional scenarios. The objective is, however, to be applicable to real scenarios. Before attempting to use classified data to model realistic scenarios, we suggest some refinements like the ones described above and further testing on a lot more capable computers to reduce the processing time. To address real life problems, specialized CFAM input files will also be

necessary. Another area for further research is weapons allocation in addition to aircraft allocation at more complicated levels.

Future efforts should focus on discovering alternative ways to determine various weights of the scenarios. Enough consideration should be given to whether or not there are other methods to perform a thorough sensitivity analysis to address this problem. If there are, the question about the method of employment should be given an adequate answer.

Appendix 1: Scatter Search Code with Evaluation Function

```
/*              File : scattersearch.c
*/

#include "ocl.h"
#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <string.h>
#include <fcntl.h>
#include <io.h>
/*
        CFAM Multi-Scenario Evaluation Function for OptQuest

        Written By:  Gokay Bulut

        Language:  C/C++

        Sources used:  C/C++ manuals
                       OptQuest manual
                       Eval.c (Bennett, 2000:51)
*/

#define NUM_VARIABLES 5

double evaluate(double *);

int main(int argc,char *argv[])
{
        double DecVar[NUM_VARIABLES+1];
        double ObjVal, Boundary;
        long   Example, nsol, status;
        int    i, TotalIter;

        if (argc != 3)
        {
                printf("usage: scattersearch <total-iter> <boundary>\n");
                exit(1);
        }
        TotalIter = atoi(argv[1]);
        Boundary  = atof(argv[2]);
```

```
/* Allocating memory */
Example = OCLSetup(NUM_VARIABLES,0,0,"MAX", 536831);
if (Example < 0) {
        printf("OCLSetup error code %d\n", Example);
        exit(1);
}

/* Defining variables */
for (i = 1; i <= NUM_VARIABLES; i++) {
        status = OCLDefineVar(Example, i, 0, OCLNULL, 63,"DIS", 1);
        if (status < 0) {
                printf("OCLDefineVar error code %d\n", status);
                exit(1);
        }
}

/* Set parameters and initialize the population */
status = OCLSetSolutions(Example, TotalIter);
if (status < 0) {
        printf("OCLSetSolutions error code %d\n", status);
        exit(1);
}
status = OCLSetBoundFreq(Example, Boundary);
if (status < 0) {
        printf("OCLSetBoundFreq error code %d\n", status);
        exit(1);
}
status = OCLInitPop(Example);
if (status < 0) {
        printf("OCLInitPop error code %d\n", status);
        exit(1);
}

/* Generate and evaluate TotalIter solutions */
for (i = 1; i <= atoi(argv[1]); i++)
{
        nsol = OCLGetSolution(Example,DecVar);
        if (nsol < 0) {
                printf("OCLGetSolution error code %d\n", nsol);
                exit(1);
        }
        ObjVal = evaluate(DecVar);
        status = OCLPutSolution(Example,nsol,&ObjVal,(double*)OCLNULL);
        if (status < 0) {
                printf("OCLPutSolution error code %d\n", status);
                exit(1);
```

```
            }
            if (!(i%1000)) {
                status = OCLGetBest(Example,DecVar,&ObjVal);
                if (status < 0) {
                    printf("OCLGetBest error code %d\n", status);
                    exit(1);
                }
                printf("Best solution after %7d iterations is %9.6f\n",i,ObjVal);
            }
        }

        /* Display the best solution found */
        status = OCLGetBest(Example,DecVar,&ObjVal);
        if (status < 0) {
            printf("OCLGetBest error code %d\n", status);
            exit(1);
        }
        printf("\n");
        for(i=1;i<=NUM_VARIABLES;i++) printf("x[%2d] = %9.6lf\n",i, DecVar[i]);

        /* Free memory */
        status = OCLGoodBye(Example);
        if (status < 0) {
            printf("OCLGoodBye error code %d\n", status);
            exit(1);
        }
        return 0;
}

/* Evaluation function */

double evaluate(double *vect)


{
        FILE *Instream, *Outstream, *fopen();
        float sumf;
        double sum;

/*
                    Print candidate force structures suggested
                    by OptQuest to the file 'numac.txt'
*/
        Outstream = fopen("numacft.txt", "w+");
        fprintf(Outstream,"%5.0f%5.0f%5.0f%5.0f%5.0f\n",vect[1], vect[2],
        vect[3], vect[4], vect[5]);
```

```
        fclose(Outstream);
        printf("%8.3f%8.3f%8.3f%8.3f%8.3f\n",vect[1], vect[2], vect[3],
        vect[4], vect[5]);

/*
                        Call controller interface batch file for CFAM evaluations
*/
        system("master");


/*                      Read the multi-scenario objective function value
                        from the file 'evalue.txt'.

*/


        Instream = fopen("evalue.txt", "r");
        fscanf(Instream, "%10f", &sumf);
        sum=sumf;
        fclose(Instream);
        return (sum);
}
```

Appendix 2: CFAM Evaluation Runs for Boundary Strategy Selection
Experiment 1, with Strategy 0.2

	Aircraft Number by Type					Fitness Value			Total	
Trials	**A1**	**A2**	**A3**	**A4**	**A5**	**Scenario1**	**Scenario2**	**Scenario3**	**Fitness**	**sorted**
1	32	32	32	32	32	2014	-8024.5	2025	-1328.5	4644.833
2	0	0	0	0	0	-267.5	-277	-250	-264.833	3766.167
3	63	63	63	63	63	-5665.5	-5679	-5631	-5658.5	3484.333
4	61	58	3	41	1	1911.5	-8171.5	-8150.5	-4803.5	2854
5	8	62	5	34	56	1703	-8296	-8293.5	-4962.17	2723.333
6	8	62	5	34	56	1828	1784.5	1837	1816.5	2546.667
7	59	6	37	2	52	2235	-7815	2240.5	-1113.17	2385.167
8	58	60	49	3	38	-395	-10441	-344.5	-3726.83	2324.833
9	58	60	49	3	38	-382.5	-10425	-376	-3727.83	2291.833
10	57	14	41	17	43	1395	-8626.5	1428	-1934.5	1816.5
11	61	0	33	0	61	2281	-7773	2278.5	-1071.17	1811.167
12	36	63	63	63	4	-1408	-11460.5	-1401	-4756.5	1767
13	50	9	42	18	34	2334	-7693.5	2398.5	-987	1158.167
14	63	3	32	0	63	1969	-8078	1982.5	-1375.5	1137.833
15	11	16	60	63	0	2543.5	-7513	2592	-792.5	771.3333
16	59	21	33	19	49	927	-9087.5	-9070	-5743.5	585.5
17	59	0	41	0	55	2286.5	2266.5	2322.5	2291.833	365.3333
18	61	63	0	58	0	937	-9113	943	-2411	214.1667
19	44	5	34	8	52	2821	-7193.5	2848.5	-508	156
20	63	7	40	0	52	1937	-8105.5	1949.5	-1406.33	-68.6667
21	0	0	0	31	55	5734	-4316	5737.5	2385.167	-217.833
22	50	14	35	3	52	2413.5	-7666	-7650	-4300.83	-264.833
23	63	0	39	1	52	2285.5	-7764.5	2291.5	-1062.5	-369.167
24	23	40	30	33	32	2134	-7915	2141.5	-1213.17	-484.667
25	23	40	30	33	32	2115	-7927.5	2126	-1228.83	-508
26	63	6	46	3	63	946.5	-9069.5	-9052.5	-5725.17	-606.333
27	60	21	38	25	54	144.5	134	189.5	156	-626.833
28	58	0	36	0	50	2866.5	2821.5	2874	2854	-710
29	42	25	26	13	53	2081.5	-7966	2094	-1263.5	-783.5
30	25	43	16	23	55	1939	-8115.5	1936.5	-1413.33	-792.5
31	7	63	4	35	56	1816.5	1779	1838	1811.167	-794.833
32	8	63	5	34	56	1778.5	1735	1787.5	1767	-877.833
33	63	0	63	0	0	3778	3734	3786.5	3766.167	-960.333
34	63	0	63	0	0	3568.5	-6356.5	-6339	-3042.33	-971.167
35	59	24	41	2	47	1332	-8690	-8663	-5340.33	-976.833
36	58	42	45	3	43	479	-9566.5	484	-2867.83	-983.667
37	58	63	50	3	37	-525	-10570.5	-526.5	-3874	-987
38	58	63	50	3	37	-534	-10575	-526	-3878.33	-1044.33
39	59	0	36	2	54	2467.5	-7575	2474	-877.833	-1062.5
40	59	3	36	2	53	2387	-7661.5	2393.5	-960.333	-1071.17
41	36	48	58	61	12	-714	-10763.5	-707.5	-4061.67	-1113.17

42	36	48	58	61	12	-750	-10781	-699.5	-4076.83	-1213.17
43	18	2	54	63	9	2710	2704	2756	2723.333	-1228.83
44	42	59	53	53	12	-970.5	-10973	-916.5	-4286.67	-1263.5
45	42	59	53	53	12	-957.5	-10985	-894	-4278.83	-1328.5
46	63	58	0	33	0	2314	2304	2356.5	2324.833	-1375.5
47	37	39	39	53	26	246	-9747.5	-9741.5	-6414.33	-1406.33
48	39	63	63	63	0	-1365.5	-11400	-1332.5	-4699.33	-1413.33
49	2	0	0	17	63	5877	-4139.5	5902.5	2546.667	-1441.33
50	38	54	59	52	20	-1031	-11116	-11096.5	-7747.83	-1457.17
51	38	63	59	63	6	-1437	-11488	-1397	-4774	-1461.83
52	32	27	32	23	39	2338	-7693	2404	-983.667	-1694
53	32	27	32	23	39	2370	-7668.5	2385	-971.167	-1934.5
54	25	34	57	37	7	1959.5	-8049.5	-8036.5	-4708.83	-1947.33
55	39	59	60	61	27	-2271.5	-2290.5	-2242.5	-2268.17	-1958.83
56	37	59	58	61	0	-703.5	-728.5	-698	-710	-1959.17
57	24	60	54	49	13	-25	-10039.5	-1.5	-3355.33	-1986
58	52	58	63	63	13	-2459.5	-12478.5	-2445.5	-5794.5	-2253.33
59	52	58	63	63	13	-2439.5	-2446.5	-2399	-2428.33	-2268.17
60	43	59	56	58	15	-1485.5	-11555	-1499	-4846.5	-2411
61	33	59	62	63	11	-1393.5	-11440	-1343.5	-4725.67	-2428.33
62	63	60	46	0	40	-449	-10491.5	-394	-3778.17	-2761
63	36	18	38	52	9	2368.5	-7674	2375	-976.833	-2867.83
64	4	8	63	63	11	2534.5	-7485.5	2566.5	-794.833	-3042.33
65	4	8	63	63	11	2536.5	-7473	2586	-783.5	-3355.33
66	14	9	37	50	25	3186.5	-6801	-6797	-3470.5	-3407.17
67	14	9	37	50	25	3255.5	-6758.5	3297	-68.6667	-3470.5
68	0	0	0	0	63	6912.5	-3141.5	-3128.5	214.1667	-3704.5
69	2	0	1	13	59	6320.5	-3722.5	-3705.5	-369.167	-3726.83
70	63	63	63	63	0	-2495	-12569.5	-12549.5	-9204.67	-3727.83
71	42	38	59	63	5	-373	-10394	-346.5	-3704.5	-3758.33
72	23	22	49	59	20	1336	-8693.5	1399.5	-1986	-3778.17
73	23	22	49	59	20	1376	-8678	1425.5	-1958.83	-3874
74	35	41	26	28	42	1364	-8631.5	1425.5	-1947.33	-3878.33
75	19	9	29	44	7	4641.5	4619	4674	4644.833	-3986
76	21	17	63	63	13	1107.5	-8879.5	-8863.5	-5545.17	-3990.83
77	34	30	58	63	28	-639.5	-10686	-632.5	-3986	-4061.67
78	34	30	58	63	28	-600	-634.5	-584.5	-606.333	-4076.83
79	12	4	53	63	0	3474.5	3468.5	3510	3484.333	-4278.83
80	16	8	54	63	5	2679	-7329.5	-7322	-3990.83	-4286.67
81	16	25	52	51	23	1619	-8380	1679	-1694	-4300.83
82	24	1	58	63	0	2723	-7328.5	2725	-626.833	-4699.33
83	4	63	2	22	63	2275	-7733	2325	-1044.33	-4708.83
84	33	34	54	43	22	780	740.5	793.5	771.3333	-4725.67
85	7	0	56	63	0	3704	-6331.5	3723.5	365.3333	-4756.5
86	63	63	48	0	50	-1208	-11235	-11218	-7887	-4774
87	42	39	2	36	19	3131.5	-6915	3130	-217.833	-4803.5
88	22	19	2	30	37	4489	-5535.5	4521	1158.167	-4846.5
89	62	61	33	52	1	-434	-10451	-390	-3758.33	-4962.17

90	51	49	13	38	11	1859.5	-8145.5	1900.5	-1461.83	-5340.33
91	42	41	22	35	22	1865	-8146.5	1910	-1457.17	-5545.17
92	42	41	22	35	22	1895	-8137.5	1918.5	-1441.33	-5658.5
93	16	16	48	16	48	2863	-7185.5	2868.5	-484.667	-5725.17
94	63	63	0	63	0	583.5	-9460	593.5	-2761	-5743.5
95	62	61	2	52	1	1077	-8944.5	1107.5	-2253.33	-5794.5
96	41	39	2	27	1	4459.5	-5545.5	4499.5	1137.833	-6414.33
97	20	19	1	14	0	7233	-2749	-2727.5	585.5	-7747.83
98	62	61	33	52	32	-2120	-12040	-12022	-8727.33	-7887
99	62	61	33	52	32	-1951.5	-1981	-1945	-1959.17	-8727.33
100	61	58	27	52	3	-81.5	-10095.5	-44.5	-3407.17	-9204.67
										ave -2003

Experiment 2, with Strategy 0.3

	Aircraft Number by Type						Fitness Value		Total	
Trials	A1	A2	A3	A4	A5	Scenario1	Scenario2	Scenario3	Fitness	sorted
1	0	0	0	0	0	10014	-24.5	10025	6671.5	8313.667
2	63	63	63	63	63	-16634	-16027	-16000	-16220.3	8055.333
3	3	0	1	25	55	-4384	5871	5919	2468.667	6865.167
4	61	58	3	41	1	-8475.5	-8171.5	-8150.5	-8265.83	6671.5
5	8	62	5	34	56	1703	-8296	-8293.5	-4962.17	5767.833
6	59	6	37	2	52	-7843.5	2234.5	2287	-1107.33	5715.5
7	38	59	59	61	13	-1422	-11515	-1459.5	-4798.83	5056.5
8	58	60	49	3	38	-11314	-10441	-344.5	-7366.5	4646
9	20	13	55	63	10	1816	-8075	1974	-1428.33	3873.667
10	0	0	0	7	12	9045	-976.5	9078	5715.5	3771.167
11	3	0	1	32	63	5078	5034.5	5057	5056.5	3758.167
12	14	3	10	1	22	-3085.5	-2460	-2451	-2665.5	3274.5
13	63	9	47	3	63	-9368.5	-9266	-9245.5	-9293.33	2602.833
14	2	4	6	27	1	8044.5	8034	8087.5	8055.333	2468.667
15	22	17	61	63	11	-8772	1273	1288.5	-2070.17	1961.167
16	13	20	20	20	4	-4026.5	-3881.5	6172.5	-578.5	1392.167
17	25	39	39	41	9	-8564	-7686	-7673.5	-7974.5	1273
18	51	61	61	62	38	-3784	-13694.5	-13675.5	-10384.7	1218.833
19	3	21	2	11	19	7163.5	7257.5	-2800	3873.667	1151.833
20	5	41	3	23	37	-5572	-5468.5	-5446.5	-5495.67	1114.5
21	36	63	34	49	60	-12096.5	-12106	-12096	-12099.5	993.6667
22	11	10	13	1	0	8253.5	8323	8364.5	8313.667	744.3333
23	43	42	45	33	32	364.5	-9788.5	-9771.5	-6398.5	726.6667
24	26	1	11	1	12	-2700	-2577.5	7510.5	744.3333	704.1667
25	63	61	60	4	50	-1839.5	-11932	-11911	-8560.83	654.8333
26	19	16	0	16	0	-2734	-2565	7479	726.6667	376.5
27	19	16	0	16	0	-3464	-2590	-2568	-2874	118.3333
28	21	21	21	21	21	4720.5	-5293	4749	1392.167	-46.5
29	42	42	42	42	42	-538.5	-10524	-10503	-7188.5	-413.667
30	22	2	13	17	54	4660	4616.5	4661.5	4646	-578.5
31	40	4	25	10	53	3468.5	-6585	3471.5	118.3333	-645.5
32	63	6	40	0	52	1971.5	-8050	1997.5	-1360.33	-655.5
33	61	6	38	1	52	2134	-7916	2138	-1214.67	-719
34	61	6	38	1	52	2134	-7916	2139.5	-1214.17	-736.833
35	5	3	21	33	47	4625.5	-5435	-5422	-2077.17	-796.167
36	22	16	63	63	2	1816	-8265	-8249.5	-4899.5	-917.333
37	9	12	7	40	51	4030	-5987.5	4070	704.1667	-1011.67
38	0	0	0	10	59	6633	-3434.5	6625	3274.5	-1012.83
39	44	63	63	63	9	-2034.5	-12071.5	-12054.5	-8720.17	-1035.83
40	3	22	2	27	55	4543.5	-5492	4605	1218.833	-1107.33
41	3	22	2	27	55	4623	-5426	4622	1273	-1111.5

42	8	63	6	36	56	1661.5	-8420.5	-8399	-5052.67	-1214.17
43	5	6	1	27	47	5779.5	5733.5	5790.5	5767.833	-1214.67
44	5	6	1	27	47	5791.5	-4282.5	-4261	-917.333	-1263.33
45	34	38	32	34	24	2019	-8063	-8046.5	-4696.83	-1282.17
46	21	25	2	16	47	4449	-5576	4470.5	1114.5	-1282.83
47	21	25	2	16	47	4493	-5549	4511.5	1151.833	-1308.33
48	63	63	50	0	30	-172	-10262	-10248	-6894	-1347.67
49	6	4	2	29	40	5944	-4078	-4076.5	-736.833	-1360.33
50	0	0	0	21	63	-4200	-4188.5	-4166	-4184.83	-1370.17
51	0	0	0	21	63	5919	-4162	-4145.5	-796.167	-1379
52	63	62	4	45	0	1254	-8742.5	1300.5	-2062.67	-1385
53	0	0	0	9	55	6868.5	6837	6890	6865.167	-1420.33
54	48	8	42	5	49	2466	-7575.5	-7553.5	-4221	-1428.33
55	63	4	32	0	55	2333.5	-7714	2342	-1012.83	-1551.33
56	9	15	60	63	7	2337	-7713.5	2341.5	-1011.67	-2047.67
57	9	15	60	63	7	2287.5	-7724.5	2329.5	-1035.83	-2061.67
58	63	1	30	0	55	2613	2569.5	2626	2602.833	-2062.67
59	30	63	63	63	10	-1413	-11461.5	-1406.5	-4760.33	-2070.17
60	30	63	63	63	10	-1455	-11491.5	-1393.5	-4780	-2077.17
61	42	25	26	13	53	2089	-7965.5	2086.5	-1263.33	-2084.83
62	25	43	16	23	55	1966.5	1929	1988	1961.167	-2665.5
63	0	63	0	63	63	633	640	691.5	654.8333	-2804.5
64	63	0	63	0	0	3784	3743.5	3786	3771.167	-2874
65	61	3	50	1	26	2818.5	-7106.5	-7089	-3792.33	-2941.33
66	53	18	36	6	43	2182	-7840	-7813	-4490.33	-2941.67
67	63	0	38	0	61	1926.5	-8124	1936.5	-1420.33	-3412.83
68	26	44	31	36	23	2042	-8013.5	2046.5	-1308.33	-3727.67
69	59	23	43	2	48	1249	-8779	1275.5	-2084.83	-3792.33
70	59	0	31	2	56	2630.5	-7416.5	2629	-719	-3887.17
71	58	63	55	3	34	-611.5	-10659	-605	-3958.5	-3888.5
72	60	23	26	15	35	2060.5	-7979.5	2072.5	-1282.17	-3958.5
73	60	41	14	28	18	1969	-8079	1973	-1379	-4184.83
74	61	59	2	42	0	1771	-8237.5	1812.5	-1551.33	-4221
75	61	59	2	42	0	1753	-8246.5	-8244	-4912.5	-4490.33
76	59	3	39	0	55	2153	-7846	-7849	-4514	-4514
77	59	3	39	0	55	2237	-7813.5	2242	-1111.5	-4609.33
78	60	20	39	28	55	-65	-10114.5	-59	-3412.83	-4696.83
79	60	20	39	28	55	-28.5	-79	-32	-46.5	-4720.67
80	58	0	35	0	49	2930.5	-7115.5	2944	-413.667	-4760.33
81	32	44	58	62	12	-402.5	-10441	-339.5	-3727.67	-4780
82	63	63	63	0	63	-2597	-12641	-2546.5	-5928.17	-4798.83
83	51	61	61	31	38	-2056.5	-2068	-2018.5	-2047.67	-4899.5
84	51	61	61	31	38	-2065	-2085.5	-2034.5	-2061.67	-4912.5
85	10	7	28	63	5	-5684.5	4324	4341.5	993.6667	-4962.17
86	16	29	38	53	25	1963.5	-8068.5	-8057	-4720.67	-5052.67
87	16	29	38	53	25	1982	-8075	1982.5	-1370.17	-5495.67
88	0	63	0	0	63	3759.5	3728	3787	3758.167	-5928.17
89	4	63	3	17	60	2692.5	-7343.5	2714.5	-645.5	-6398.5

90	4	63	3	17	60	2694	-7357.5	2697	-655.5	-6894
91	63	0	63	63	0	527	-9495.5	555	-2804.5	-7188.5
92	24	19	47	53	17	1986	-8043.5	2014.5	-1347.67	-7366.5
93	28	26	40	42	25	1952.5	-8080.5	1973	-1385	-7974.5
94	44	52	8	0	55	2059	-7980	2072.5	-1282.83	-8265.83
95	38	42	20	16	43	2087	-7965	-7950	-4609.33	-8560.83
96	0	0	63	63	0	3730.5	-6328	3727	376.5	-8720.17
97	10	7	59	63	5	2793	-7237	-7217.5	-3887.17	-9293.33
98	10	7	59	63	5	2771.5	-7227	-7210	-3888.5	-10384.7
99	45	44	51	23	29	397.5	-9638	415.5	-2941.67	-12099.5
100	45	44	51	23	29	397	-9635.5	414.5	-2941.33	-16220.3
										ave
										-1820.17

Experiment 3, with Strategy 0.5

	Aircraft Number by Type						Fitness Value		Total	
Trials	A1	A2	A3	A4	A5	Scenario1	Scenario2	Scenario3	Fitness	sorted
1	0	0	0	0	0	10014	-24.5	10025	6671.5	6671.5
2	0	0	0	0	0	-267.5	-277	-250	-264.833	6046
3	3	0	1	25	55	5884.5	5871	5919	5891.5	5990.5
4	61	58	3	41	1	1911.5	-8171.5	-8150.5	-4803.5	5891.5
5	8	62	5	34	56	1703	-8296	-8293.5	-4962.17	3514
6	38	59	59	61	13	-1465	-11515	-1459.5	-4813.17	3489.333
7	58	60	49	3	38	-395	-10441	-344.5	-3726.83	3340.333
8	20	13	55	63	10	1967.5	-8075	1974	-1377.83	3327.5
9	20	13	55	63	10	1945	-8076.5	1978	-1384.5	3182.5
10	0	0	0	15	53	6690.5	-3380.5	6672.5	3327.5	2794.833
11	10	15	10	27	45	4712	-5323.5	-5306.5	-1972.67	2584.333
12	0	0	0	23	63	5740	-4292.5	5763.5	2403.667	2403.667
13	0	0	0	23	63	5819.5	-4263	-4245.5	-896.333	2314.5
14	39	47	41	34	22	844	-9180.5	865.5	-2490.33	2271
15	40	40	33	10	44	1687	-8347	1704	-1652	2223.333
16	61	63	51	2	37	-670.5	-10720	-676	-4022.17	2093.833
17	61	63	51	2	37	-685	-10724.5	-676	-4028.5	1795.833
18	0	0	0	63	63	3825.5	-6260.5	3794.5	453.1667	1403.5
19	22	19	2	30	37	4624	-5463.5	-5454	-2097.83	1184.167
20	42	39	2	36	19	3116	-6901	3160	-208.333	1154.833
21	63	63	63	63	0	-2611	-12635.5	-2579	-5941.83	1121.167
22	62	61	33	52	1	-473	-10494	-446.5	-3804.5	1119
23	15	20	20	37	41	3309.5	-6695.5	3350.5	-11.8333	602
24	26	39	40	49	27	993.5	-9049.5	1003.5	-2350.83	453.1667
25	51	61	61	62	7	-2068.5	-2091	-2031.5	-2063.67	387
26	5	21	2	28	55	4439.5	-5587.5	4505	1119	121.6667
27	6	41	4	31	56	3168.5	-6876	3171.5	-178.667	-11.8333
28	36	63	34	49	60	-2028	-12095.5	-2043	-5388.83	-63
29	2	0	1	24	55	5984	5973	6014.5	5990.5	-178.667
30	4	0	1	26	55	5811.5	-4270	-4253.5	-904	-208.333
31	28	0	9	18	54	4660.5	-5423	-5397	-2053.17	-264.833
32	0	0	0	32	56	5666	-4386.5	5664	2314.5	-369.167
33	63	6	45	0	51	1870	-8217	-8199	-4848.67	-412.167
34	9	4	19	38	40	4533	-5516.5	4536	1184.167	-597.333
35	14	9	37	50	25	3312.5	-6741.5	-6728.5	-3385.83	-611.167
36	42	38	59	63	5	-344.5	-10358.5	-303	-3668.67	-670.5
37	0	0	0	0	63	6836	-3193.5	6899.5	3514	-712.167
38	2	0	1	13	59	6320.5	-3722.5	-3705.5	-369.167	-736.333
39	53	53	53	53	53	-3145	-13219.5	-13199.5	-9854.67	-816.333
40	42	42	42	42	42	-420	-429	-387.5	-412.167	-896.333
41	16	16	16	16	16	6060	6016.5	6061.5	6046	-904

42	61	62	58	43	55	-3995	-13977	-13959.5	-10643.8	-1126.67
43	60	61	54	23	46	-2119	-2127	-2086	-2110.67	-1133
44	60	61	54	23	46	-2155	-2178	-2132	-2155	-1168.83
45	58	60	49	2	37	-286.5	-10323.5	-276	-3628.67	-1275.33
46	58	60	49	2	37	-285	-10324.5	-276	-3628.5	-1377.83
47	62	60	23	48	22	-679.5	-691	-641	-670.5	-1384.5
48	61	58	2	41	0	1910.5	-8131.5	1954.5	-1422.17	-1422.17
49	60	62	62	63	54	-5097.5	-15096	-15098	-11763.8	-1527.5
50	35	58	58	61	4	-719.5	-729.5	-687.5	-712.167	-1652
51	35	58	58	61	4	-817.5	-10843	-791.5	-4150.67	-1869.83
52	26	62	24	44	58	-615.5	-632	-586	-611.167	-1909.67
53	4	31	3	17	28	5933	-4150	5970	2584.333	-1934.83
54	4	31	3	17	28	5861.5	-4163	-4147.5	-816.333	-1972.67
55	63	43	54	49	59	-3438.5	-13424	-13403	-10088.5	-2029.5
56	59	0	28	0	48	3333.5	3323	3364.5	3340.333	-2038.17
57	59	0	28	0	48	3279.5	-6762.5	3294	-63	-2053.17
58	17	3	55	63	0	3174	3163	3210.5	3182.5	-2063.67
59	41	44	33	21	35	1261	-8729.5	-8717	-5395.17	-2097.83
60	41	44	33	21	35	1309.5	-8720.5	1322.5	-2029.5	-2110.67
61	63	63	50	0	41	-824.5	-10868.5	-811	-4168	-2155
62	63	63	50	0	41	-830	-10874	-824.5	-4176.17	-2307
63	31	30	42	30	41	1296.5	-8734.5	1323.5	-2038.17	-2350.83
64	62	60	0	43	0	1792	1765.5	1830	1795.833	-2474.67
65	62	60	0	43	0	1703	-8302	-8289.5	-4962.83	-2490.33
66	29	21	29	20	32	3488	3463.5	3516.5	3489.333	-2998.83
67	29	21	29	20	32	3450.5	-6575	3489.5	121.6667	-3385.83
68	25	40	25	32	34	2210.5	2203.5	2256	2223.333	-3628.5
69	25	40	25	32	34	2220	-7826.5	2226.5	-1126.67	-3628.67
70	1	63	0	34	58	2210	-7832.5	2223.5	-1133	-3642.67
71	1	63	0	34	58	2278	2241	2294	2271	-3655.33
72	19	29	22	17	29	4203	-5819	-5808	-2474.67	-3668.67
73	41	23	34	22	39	2100	2064	2117.5	2093.833	-3726.83
74	41	23	34	22	39	2069	-7978	2083	-1275.33	-3777.33
75	50	15	35	12	45	2181.5	-7868.5	2180.5	-1168.83	-3777.67
76	61	3	50	1	58	1393.5	1380.5	1436.5	1403.5	-3804.5
77	0	63	0	63	0	3739.5	-6315.5	3737	387	-4022.17
78	0	63	0	63	0	3663.5	-6337.5	-6322.5	-2998.83	-4028.5
79	29	23	38	36	22	2596.5	-7429.5	2624	-736.333	-4150.67
80	35	41	26	28	42	1396.5	-8631.5	1430.5	-1934.83	-4168
81	17	4	61	63	0	2791.5	2769	2824	2794.833	-4176.17
82	17	4	61	63	0	2714	-7281.5	2775.5	-597.333	-4488.67
83	58	61	63	0	49	-1544	-11581.5	-1533.5	-4886.33	-4803.5
84	61	57	0	53	0	1480.5	-8565	1475	-1869.83	-4813.17
85	61	57	0	53	0	1411	-8591.5	1451.5	-1909.67	-4823.5
86	45	59	56	42	21	-1151.5	-11175	-1139.5	-4488.67	-4828.33
87	37	59	59	63	12	-1499	-11526	-1445.5	-4823.5	-4848.67
88	37	59	59	63	12	-1494	-11541.5	-1449.5	-4828.33	-4886.33
89	38	59	59	62	13	-1542	-1546	-1494.5	-1527.5	-4962.17

90	59	60	49	2	39	-433.5	-10474	-425.5	-3777.67	-4962.83
91	59	60	49	2	39	-432	-10474.5	-425.5	-3777.33	-5142.33
92	25	61	20	24	50	1030.5	-9019	1067.5	-2307	-5388.83
93	0	63	0	63	63	606.5	576	623.5	602	-5395.17
94	4	63	3	49	60	1133	1140	1191.5	1154.833	-5941.83
95	4	63	3	49	60	1134	1093.5	1136	1121.167	-9854.67
96	61	30	56	2	19	1468.5	-8456.5	-8439	-5142.33	-10088.5
97	39	40	33	2	25	3006.5	-6993	-6979.5	-3655.33	-10643.8
98	39	40	33	2	25	3031	-6990	-6969	-3642.67	-11763.8
										average
										-1548.71

Experiment 4, with Strategy 0.8

	Aircraft Number by Type					Fitness Value			Total	
Trials	A1	A2	A3	A4	A5	Scenario1	Scenario2	Scenario3	Fitness	sorted
1	0	0	0	0	0	-191.5	-24.5	10025	3269.667	6893.667
2	0	0	0	0	0	-267.5	-277	-250	-264.833	6140.667
3	3	0	1	25	55	5884.5	5871	5919	5891.5	6063.5
4	61	58	3	41	1	1911.5	-8171.5	-8150.5	-4803.5	5990.5
5	8	62	5	34	56	1703	-8296	-8293.5	-4962.17	5891.5
6	59	6	37	2	52	2278	2234.5	2287	2266.5	4818
7	38	59	59	61	13	-1465	-11515	-1459.5	-4813.17	4199.833
8	58	60	49	3	38	-395	-10441	-344.5	-3726.83	3770.833
9	20	13	55	63	10	1967.5	-8075	1974	-1377.83	3522
10	20	13	55	63	10	1945	-8076.5	1978	-1384.5	3269.667
11	0	0	0	31	56	5745	-4327.5	-4305	-962.5	2497.833
12	63	7	43	0	51	1915	-8171.5	-8149	-4801.83	2266.5
13	23	21	22	38	58	1933	-8116.5	1936.5	-1415.67	1149.333
14	43	42	42	50	60	-1786	-1810	-1751.5	-1782.5	1119
15	43	42	42	50	60	-1766	-1778	-1732.5	-1758.83	993.6667
16	2	0	1	13	28	-2208.5	-2196	-2174.5	-2193	602
17	22	21	22	30	40	3292.5	-6750	3315	-47.5	453.1667
18	63	63	63	63	0	-2576.5	-12605.5	-2556	-5912.67	374.6667
19	48	48	48	48	16	-423	-10444	-396.5	-3754.5	372.1667
20	0	0	0	0	63	6846.5	-3188	6907.5	3522	371.6667
21	2	0	1	13	59	6320.5	-3722.5	-3705.5	-369.167	-11.8333
22	21	20	17	18	49	3855	-6219.5	-6199.5	-2854.67	-47.5
23	40	40	33	10	44	1687	-8347	1704	-1652	-178.667
24	40	40	33	10	44	1679.5	-8370	1674	-1672.17	-208.333
25	59	62	50	2	38	-535	-10574.5	-526	-3878.5	-241.833
26	0	0	0	63	63	3716.5	-6324.5	3724.5	372.1667	-264.833
27	0	0	0	63	63	3825.5	-6260.5	3794.5	453.1667	-369.167
28	22	19	2	30	37	4624	-5463.5	-5454	-2097.83	-409
29	42	39	2	36	19	3116	-6901	3160	-208.333	-421.833
30	42	39	2	36	19	3089	-6935.5	3121	-241.833	-428
31	15	20	20	37	41	3309.5	-6695.5	3350.5	-11.8333	-434.333
32	26	39	40	49	27	993.5	-9049.5	1003.5	-2350.83	-565.667
33	51	61	61	62	7	-2068.5	-2091	-2031.5	-2063.67	-640.833
34	5	21	2	28	55	4439.5	-5587.5	4505	1119	-681.833
35	6	41	4	31	56	3168.5	-6876	3171.5	-178.667	-708.5
36	36	63	34	49	60	-2028	-12095.5	-2043	-5388.83	-772.5
37	2	0	1	24	55	5984	5973	6014.5	5990.5	-903.167
38	4	0	1	26	55	5811.5	-4270	-4253.5	-904	-904
39	4	0	1	26	55	5810.5	-4273	-4247	-903.167	-962.5
40	0	0	0	13	63	6283	-3790	-3777	-428	-1097.33
41	28	13	63	63	0	1761	-8318.5	-8297	-4951.5	-1125.67

42	28	13	63	63	0	1627	-8391	1668	-1698.67	-1212.83
43	62	44	54	43	59	-3032.5	-3067	-3030.5	-3043.33	-1220.5
44	30	3	19	1	26	6133.5	6123.5	6165	6140.667	-1255.67
45	30	3	19	1	26	6010	-3975	-3957.5	-640.833	-1262.83
46	41	23	34	22	39	2081.5	-7968.5	2080.5	-1268.83	-1268.83
47	0	63	0	63	0	3719	-6328	3733	374.6667	-1372.17
48	16	48	16	48	16	2763.5	-7237.5	-7222.5	-3898.83	-1377.83
49	61	4	37	0	53	2213.5	-7779.5	2274	-1097.33	-1384.5
50	60	5	37	1	53	2196.5	-7814.5	2241	-1125.67	-1398
51	59	24	41	2	47	-8839.5	-8664.5	1391	-5371	-1415.67
52	58	42	45	3	43	485	-9566.5	484	-2865.83	-1430.33
53	58	63	50	3	37	-521	-10570.5	-526.5	-3872.67	-1512.67
54	58	62	49	3	38	-476.5	-10525	-476	-3825.83	-1652
55	63	0	0	0	63	3716	-6325	3724	371.6667	-1672.17
56	61	3	19	1	58	2917.5	-7096.5	2952	-409	-1698.67
57	60	23	26	15	35	2092.5	-7956	2096.5	-1255.67	-1758.83
58	60	41	14	28	18	1989.5	-8079	1973	-1372.17	-1782.5
59	61	59	2	42	0	-8384	-8237.5	1812.5	-4936.33	-1928.17
60	61	59	3	41	1	1703	-8296.5	-8294	-4962.5	-1938.5
61	59	3	39	0	55	-8702.5	-7846	-7849	-8132.5	-2063.67
62	59	5	38	1	53	-7849	-7813.5	2242	-4473.5	-2097.83
63	57	19	45	15	45	-9952.5	-9064.5	991	-6008.67	-2152.67
64	61	0	29	0	59	2585	-7477	2574.5	-772.5	-2193
65	36	63	63	63	6	-11748.5	-11558.5	-1500	-8269	-2320.67
66	42	25	26	13	53	2100	-7993	2104.5	-1262.83	-2350.83
67	25	43	16	23	55	1888	-8115.5	1936.5	-1430.33	-2854.67
68	0	63	0	63	63	589	579	638	602	-2865.83
69	4	63	3	49	60	1116.5	1140	1191.5	1149.333	-2911.17
70	63	0	63	0	0	3783	3743.5	3786	3770.833	-3043.33
71	61	3	50	1	26	3034	-7106.5	-7089	-3720.5	-3720.5
72	39	4	25	1	35	4668.5	-5240	-5213	-1928.17	-3726.83
73	20	2	12	1	17	-3514	-2615	-2604.5	-2911.17	-3754.5
74	63	6	40	2	56	1643.5	-8376	-8355	-5029.17	-3825.83
75	61	6	38	2	54	1879.5	-8066	1992.5	-1398	-3872.67
76	58	8	43	16	39	1838.5	-8215.5	1839	-1512.67	-3878.5
77	60	4	31	0	63	2137	-7929.5	2131	-1220.5	-3898.83
78	19	15	61	63	0	2125	-7911.5	2148	-1212.83	-4076.83
79	53	53	53	53	53	-14152.5	-13286.5	-3229	-10222.7	-4473.5
80	42	42	42	42	42	-11414	-429	-387.5	-4076.83	-4801.83
81	16	16	16	16	16	6112.5	6016.5	6061.5	6063.5	-4803.5
82	61	62	58	43	55	-3890	-13977	-13959.5	-10608.8	-4813.17
83	60	61	54	23	46	-2245	-2127	-2086	-2152.67	-4936.33
84	29	30	25	2	19	4864	4772	4818	4818	-4951.5
85	62	61	43	56	42	-3155	-13238.5	-13219.5	-9871	-4962.17
86	62	60	23	48	22	-793.5	-691	-641	-708.5	-4962.5
87	31	29	2	21	1	5870.5	-4231.5	5854.5	2497.833	-5029.17
88	55	62	62	62	46	-4339.5	-14395.5	-14380.5	-11038.5	-5371
89	46	60	60	62	30	-13076.5	-2831.5	-2789	-6232.33	-5388.83

90	19	30	30	31	7	4225.5	4162	4212	4199.833	-5912.67
91	60	63	42	56	61	-4046.5	-14140	-14119	-10768.5	-6008.67
92	60	63	42	56	61	-14284	-4027.5	-3986	-7432.5	-6232.33
93	5	62	0	27	54	2668.5	-7405.5	2691.5	-681.833	-7432.5
94	21	21	21	21	21	4711.5	-5274	-5253	-1938.5	-8132.5
95	34	30	58	63	28	-575.5	-581.5	-540	-565.667	-8269
96	0	0	0	63	0	6900	6865.5	6915.5	6893.667	-9871
97	10	7	28	63	5	-5684.5	4324	4341.5	993.6667	-10222.7
98	10	7	28	63	5	4363.5	-5668.5	-5657	-2320.67	-10608.8
99	25	24	28	33	32	2913	-7133	2917	-434.333	-10768.5
100	25	24	28	33	32	2915	-7119.5	2939	-421.833	-11038.5
										average
										-1837.59

<u>Appendix 3: Test Experiment with 249 runs</u>

	Aircraft Number by Type					Fitness Value			Total			
Trials	A1	A2	A3	A4	A5	Scenario1	Scenario2	Scenario3	Fitness	rank	max	sorted
1	0	0	0	0	0	10014	-24.5	10025	6671.5	5	8313.667	8313.667
2	63	63	63	63	63	-16634	-16027	-16000	-16220.3	249		8055.333
3	3	0	1	25	55	-4384	5871	5919	2468.667	34	Online	7593.333
4	61	58	3	41	1	-8475.5	-8171.5	-8150.5	-8265.83	238	-2993.81	6865.167
5	8	62	5	34	56	1703	-8296	-8293.5	-4962.17	217	-2143.31	6390.833
6	59	6	37	2	52	-7843.5	2234.5	2287	-1107.33	110	-1718.64	5987.667
7	38	59	59	61	13	-1422	-11515	-1459.5	-4798.83	213	-1841.26	5938.833
8	58	60	49	3	38	-11314	-10441	-344.5	-7366.5	235	-1786.97	5935.833
9	20	13	55	63	10	1816	-8075	1974	-1428.33	129	-1910.79	5801
10	0	0	0	7	12	9045	-976.5	9078	5715.5	12	-1887.14	5767.833
11	3	0	1	32	63	5078	5034.5	5057	5056.5	16	-1865.86	5715.5
12	14	3	10	1	22	-3085.5	-2460	-2451	-2665.5	165	-1733.33	5663.833
13	63	9	47	3	63	-9368.5	-9266	-9245.5	-9293.33	243	-1558.45	5418.167
14	2	4	6	27	1	8044.5	8034	8087.5	8055.333	2	-1438.93	5090.833
15	22	17	61	63	11	-8772	1273	1288.5	-2070.17	145	-1336.6	5056.5
16	13	20	20	20	4	-4026.5	-3881.5	6172.5	-578.5	95		4849
17	25	39	39	41	9	-8564	-7686	-7673.5	-7974.5	236	Offline	4839.333
18	51	61	61	62	38	-3784	-13694.5	-13675.5	-10384.7	245	8055.333	4668
19	3	21	2	11	19	7163.5	7257.5	-2800	3873.667	24	8184.5	4646
20	5	41	3	23	37	-5572	-5468.5	-5446.5	-5495.67	224	8227.556	4379.833
21	36	63	34	49	60	-12096.5	-12106	-12096	-12099.5	247	8249.083	4298.667
22	11	10	13	1	0	8253.5	8323	8364.5	8313.667	1	8262	4013.167
23	43	42	45	33	32	364.5	-9788.5	-9771.5	-6398.5	231	8270.611	3873.667
24	26	1	11	1	12	-2700	-2577.5	7510.5	744.3333	59	8276.762	3771.167
25	63	61	60	4	50	-1839.5	-11932	-11911	-8560.83	240	8281.375	3766.5
26	19	16	0	16	0	-2734	-2565	7479	726.6667	61	8284.963	3758.167
27	19	16	0	16	0	-3464	-2590	-2568	-2874	172	8287.833	3530
28	21	21	21	21	21	4720.5	-5293	4749	1392.167	45	8290.182	3484.333
29	42	42	42	42	42	-538.5	-10524	-10503	-7188.5	234	8292.139	3274.5
30	22	2	13	17	54	4660	4616.5	4661.5	4646	20		2843
31	40	4	25	10	53	3468.5	-6585	3471.5	118.3333	83	Best	2682
32	63	6	40	0	52	1971.5	-8050	1997.5	-1360.33	124	8055.333	2602.833
33	61	6	38	1	52	2134	-7916	2138	-1214.67	113	8313.667	2468.667
34	61	6	38	1	52	2134	-7916	2139.5	-1214.17	112	8313.667	2273.833
35	5	3	21	33	47	4625.5	-5435	-5422	-2077.17	146	8313.667	2109.5
36	22	16	63	63	2	1816	-8265	-8249.5	-4899.5	214	8313.667	2034.333
37	9	12	7	40	51	4030	-5987.5	4070	704.1667	65	8313.667	2000.833
38	0	0	0	10	59	6633	-3434.5	6625	3274.5	30	8313.667	1961.167
39	44	63	63	63	9	-2034.5	-12071.5	-12054.5	-8720.17	241	8313.667	1840.167
40	3	22	2	27	55	4543.5	-5492	4605	1218.833	51	8313.667	1795.167
41	3	22	2	27	55	4623	-5426	4622	1273	49	8313.667	1549.833
42	8	63	6	36	56	1661.5	-8420.5	-8399	-5052.67	218	8313.667	1546.833

43	5	6	1	27	47	5779.5	5733.5	5790.5	5767.833	11	8313.667	1397.667
44	5	6	1	27	47	5791.5	-4282.5	-4261	-917.333	105		1392.167
45	34	38	32	34	24	2019	-8063	-8046.5	-4696.83	209	Average	1376.5
46	21	25	2	16	47	4449	-5576	4470.5	1114.5	53	-2447.9	1353.167
47	21	25	2	16	47	4493	-5549	4511.5	1151.833	52	-1153.02	1285.167
48	63	63	50	0	30	-172	-10262	-10248	-6894	233	-1101.29	1273
49	6	4	2	29	40	5944	-4078	-4076.5	-736.833	100	-2385.57	1259.667
50	0	0	0	21	63	-4200	-4188.5	-4166	-4184.83	198	-1655.94	1218.833
51	0	0	0	21	63	5919	-4162	-4145.5	-796.167	102	-2845.02	1151.833
52	63	62	4	45	0	1254	-8742.5	1300.5	-2062.67	144	-1292.4	1114.5
53	0	0	0	9	55	6868.5	6837	6890	6865.167	4	-1618.65	1084.667
54	48	8	42	5	49	2466	-7575.5	-7553.5	-4221	199	-643.595	993.6667
55	63	4	32	0	55	2333.5	-7714	2342	-1012.83	107	29.56349	958.8333
56	9	15	60	63	7	2337	-7713.5	2341.5	-1011.67	106	-406.968	800
57	9	15	60	63	7	2287.5	-7724.5	2329.5	-1035.83	108	-828.5	756.8333
58	63	1	30	0	55	2613	2569.5	2626	2602.833	33		744.3333
59	30	63	63	63	10	-1413	-11461.5	-1406.5	-4760.33	211		743
60	30	63	63	63	10	-1455	-11491.5	-1393.5	-4780	212		726.6667
61	42	25	26	13	53	2089	-7965.5	2086.5	-1263.33	115		713.8333
62	25	43	16	23	55	1966.5	1929	1988	1961.167	39		708.1667
63	0	63	0	63	63	633	640	691.5	654.8333	67		706.8333
64	63	0	63	0	0	3784	3743.5	3786	3771.167	25		704.1667
65	61	3	50	1	26	2818.5	-7106.5	-7089	-3792.33	185		659.8333
66	53	18	36	6	43	2182	-7840	-7813	-4490.33	205		654.8333
67	63	0	38	0	61	1926.5	-8124	1936.5	-1420.33	128		651.3333
68	26	44	31	36	23	2042	-8013.5	2046.5	-1308.33	120		603.8333
69	59	23	43	2	48	1249	-8779	1275.5	-2084.83	147		562.6667
70	59	0	31	2	56	2630.5	-7416.5	2629	-719	99		482
71	58	63	55	3	34	-611.5	-10659	-605	-3958.5	191		457
72	60	23	26	15	35	2060.5	-7979.5	2072.5	-1282.17	117		425.1667
73	60	41	14	28	18	1969	-8079	1973	-1379	126		406.6667
74	61	59	2	42	0	1771	-8237.5	1812.5	-1551.33	133		376.5
75	61	59	2	42	0	1753	-8246.5	-8244	-4912.5	215		369.5
76	59	3	39	0	55	2153	-7846	-7849	-4514	206		343.8333
77	59	3	39	0	55	2237	-7813.5	2242	-1111.5	111		341.5
78	60	20	39	28	55	-65	-10114.5	-59	-3412.83	181		313
79	60	20	39	28	55	-28.5	-79	-32	-46.5	89		238.8333
80	58	0	35	0	49	2930.5	-7115.5	2944	-413.667	92		230.8333
81	32	44	58	62	12	-402.5	-10441	-339.5	-3727.67	183		182.6667
82	63	63	63	0	63	-2597	-12641	-2546.5	-5928.17	228		118.3333
83	51	61	61	31	38	-2056.5	-2068	-2018.5	-2047.67	142		35.83333
84	51	61	61	31	38	-2065	-2085.5	-2034.5	-2061.67	143		1.833333
85	10	7	28	63	5	-5684.5	4324	4341.5	993.6667	55		-18.5
86	16	29	38	53	25	1963.5	-8068.5	-8057	-4720.67	210		-24.3333
87	16	29	38	53	25	1982	-8075	1982.5	-1370.17	125		-33.8333
88	0	63	0	0	63	3759.5	3728	3787	3758.167	27		-46.5
89	4	63	3	17	60	2692.5	-7343.5	2714.5	-645.5	97		-274.333
90	4	63	3	17	60	2694	-7357.5	2697	-655.5	98		-334.833

91	63	0	63	63	0	527	-9495.5	555	-2804.5	170	-413.667
92	24	19	47	53	17	1986	-8043.5	2014.5	-1347.67	122	-444
93	28	26	40	42	25	1952.5	-8080.5	1973	-1385	127	-480.333
94	44	52	8	0	55	2059	-7980	2072.5	-1282.83	118	-578.5
95	38	42	20	16	43	2087	-7965	-7950	-4609.33	208	-644.667
96	0	0	63	63	0	3730.5	-6328	3727	376.5	75	-645.5
97	10	7	59	63	5	2793	-7237	-7217.5	-3887.17	187	-655.5
98	10	7	59	63	5	2771.5	-7227	-7210	-3888.5	188	-719
99	45	44	51	23	29	397.5	-9638	415.5	-2941.67	174	-736.833
100	45	44	51	23	29	397	-9635.5	414.5	-2941.33	173	-791.333
101	61	62	25	2	51	-6.5	-18.5	30.5	1.833333	85	-796.167
102	34	28	38	56	7	1884	-8164.5	1879	-1467.17	131	-867.833
103	47	43	20	48	4	1884.5	-8141.5	1918	-1446.33	130	-870.333
104	63	63	0	0	0	3661.5	-6345.5	3708.5	341.5	78	-917.333
105	63	63	0	0	0	3568.5	-6355.5	-6347	-3044.67	176	-1011.67
106	0	0	63	63	63	441	-9507	-9494.5	-6186.83	230	-1012.83
107	0	0	63	63	63	647	653.5	653.5	651.3333	68	-1035.83
108	10	7	59	63	37	1252	1234.5	1292.5	1259.667	50	-1079.5
109	49	46	60	63	45	-3100	-3134.5	-3084.5	-3106.33	177	-1107.33
110	12	4	53	63	0	3474.5	3468.5	3510	3484.333	29	-1111.5
111	16	8	54	63	5	2679	-7329.5	-7322	-3990.83	193	-1214.17
112	23	59	49	49	16	169	-9830	229	-3144	178	-1214.67
113	53	59	63	63	10	-2402.5	-12437.5	-2384.5	-5741.5	226	-1221.33
114	0	62	0	22	59	2845	-7191.5	2905.5	-480.333	94	-1263.33
115	0	62	0	22	59	2916	-7149.5	2901.5	-444	93	-1280
116	36	50	50	51	19	-295	-10338	-245.5	-3626.17	182	-1282.17
117	0	0	0	0	63	6861	-3185.5	6914.5	3530	28	-1282.83
118	0	0	0	0	63	6920.5	-3122.5	-3105.5	230.8333	81	-1285.33
119	63	63	63	63	0	-2549	-12596	-2540.5	-5895.17	227	-1308.33
120	63	63	63	63	0	-2623	-12644	-2596.5	-5954.5	229	-1337.83
121	51	61	61	62	7	-2110.5	-12137.5	-2045	-5431	221	-1347.67
122	28	59	60	63	8	-885	-884	-842	-870.333	104	-1355.33
123	28	59	60	63	8	-908	-10942	-849	-4233	200	-1360.33
124	49	59	39	60	13	-977	-11019.5	-974.5	-4323.67	201	-1370.17
125	49	59	39	60	13	-998	-11040.5	-949	-4329.17	202	-1379
126	27	59	63	62	13	-1192	-11240.5	-1147.5	-4526.67	207	-1385
127	40	59	59	62	35	-2797.5	-12795.5	-12798	-9463.67	244	-1420.33
128	40	59	59	62	35	-2687	-2738	-2644.5	-2689.83	167	-1428.33
129	36	59	59	60	0	-726.5	-10744	-696.5	-4055.67	195	-1446.33
130	0	63	0	35	61	2119	2078	2131.5	2109.5	36	-1467.17
131	43	31	42	31	27	1382.5	1347	1400	1376.5	46	-1500.83
132	30	61	20	22	56	552.5	-9484.5	568	-2788	169	-1551.33
133	30	61	20	22	56	617.5	573	621	603.8333	69	-1705.33
134	63	59	63	0	38	-1070	-1110.5	-1058	-1079.5	109	-1769
135	24	62	4	37	55	915	-9124	924.5	-2428.17	163	-1820
136	24	62	4	37	55	978.5	922.5	975.5	958.8333	56	-1864.67
137	0	62	6	31	57	2279	2244.5	2298	2273.833	35	-1883.67
138	26	62	24	44	58	-746.5	-10742.5	-699.5	-4062.83	196	-1926

139	45	63	44	53	61	-3217	-13300	-3180	-6565.67	232	-1950.5
140	4	31	3	17	28	5934.5	5918	5964	5938.833	8	-2024.83
141	41	41	38	22	34	1211.5	-8813	-8797.5	-5466.33	222	-2047.67
142	41	41	38	22	34	1208	-8831	1217	-2135.33	152	-2061.67
143	61	62	56	2	51	-1580	-11625	-1582.5	-4929.17	216	-2062.67
144	16	16	16	48	16	4434	-5614.5	4434.5	1084.667	54	-2070.17
145	16	16	16	48	16	4384	-5616.5	-5602.5	-2278.33	156	-2077.17
146	33	35	32	34	25	2051	-7984	2077	-1285.33	119	-2084.83
147	62	61	3	43	0	1586	-8475.5	1582.5	-1769	135	-2101.83
148	47	40	46	47	47	-1397	-11397	-11390	-8061.33	237	-2108.83
149	17	24	18	17	17	5423	5371	5460.5	5418.167	14	-2123
150	17	24	18	17	17	5323	-4677.5	-4659	-1337.83	121	-2130
151	60	59	18	28	13	1105	-8937	1111	-2240.33	155	-2135.33
152	63	0	0	63	0	3664.5	-6341	-6334.5	-3003.67	175	-2205.67
153	62	29	2	52	1	2675.5	-7333	2723.5	-644.667	96	-2225.5
154	58	60	53	0	41	-640.5	-10647.5	-591.5	-3959.83	192	-2240.33
155	58	60	51	2	39	-480	-10524	-475	-3826.33	186	-2278.33
156	60	61	54	23	46	-2182	-12224.5	-2175.5	-5527.33	225	-2312.5
157	61	62	58	43	55	-3905	-3928	-3882	-3905	190	-2325
158	29	30	25	2	19	4831	4823	4864	4839.333	18	-2326.5
159	29	30	25	2	19	4706.5	-5288.5	-5269.5	-1950.5	140	-2327.83
160	62	58	15	46	19	0.5	-10027	58.5	-3322.67	180	-2376.67
161	11	10	11	8	0	7950	-2054	-2040.5	1285.167	48	-2380.17
162	11	10	15	0	0	-1942	-1834.5	-1817.5	-1864.67	137	-2428.17
163	2	4	4	34	1	-2410	-2295	-2270	-2325	158	-2558.5
164	2	4	4	34	1	-2319.5	7722	7737	4379.833	21	-2665.5
165	11	9	9	16	0	-2389	-2285	-2263.5	-2312.5	157	-2672
166	12	13	16	0	0	-2166.5	-2080	-2059	-2101.83	148	-2689.83
167	0	0	0	11	62	-3813.5	-3694.5	-3676.5	-3728.17	184	-2752.5
168	8	4	7	5	13	8259	-1817.5	-1801	1546.833	43	-2788
169	8	4	7	5	13	-1932	-1868.5	-1850.5	-1883.67	138	-2804.5
170	13	11	16	1	0	-2176	-2084	-2066.5	-2108.83	149	-2806
171	13	11	16	1	0	-2210	-2088.5	-2070.5	-2123	150	-2874
172	10	17	12	2	13	-2809.5	-2732	-2716	-2752.5	168	-2941.33
173	12	3	14	0	0	8463.5	-1482	-1461	1840.167	40	-2941.67
174	3	38	2	18	41	-5225	-5134	-5112.5	-5157.17	219	-3003.67
175	9	7	10	1	0	8694	-1350.5	-1341	2000.833	38	-3044.67
176	13	13	16	1	0	-2268.5	-2188	-2160.5	-2205.67	153	-3106.33
177	11	16	15	3	0	-2415.5	-2291	-2273	-2326.5	159	-3144
178	11	16	15	3	0	-2413	-2297	-2273.5	-2327.83	160	-3186.83
179	11	4	11	0	0	-1418	-1332.5	-1315.5	-1355.33	123	-3322.67
180	8	9	8	12	15	7367	-2630.5	-2612	708.1667	63	-3412.83
181	8	9	8	12	15	7341.5	-2618.5	-2602.5	706.8333	64	-3626.17
182	14	11	18	0	0	-2317	-2186	-2173.5	-2225.5	154	-3727.67
183	14	6	13	5	15	7478	-2606	-2601.5	756.8333	58	-3728.17
184	8	14	13	0	0	8179	-1775.5	-1754	1549.833	42	-3792.33
185	8	14	13	0	0	-1904	-1789.5	-1766.5	-1820	136	-3826.33
186	8	14	9	4	6	8019.5	-2032.5	8017	4668	19	-3887.17

187	6	17	6	8	13	-2633	-2530.5	-2512	-2558.5	164	-3888.5
188	6	17	6	8	13	7431	-2524	-2507	800	57	-3903.83
189	1	3	4	21	19	7634.5	-2396.5	7658	4298.667	22	-3905
190	1	1	2	15	37	-2826	-2809.5	-2782.5	-2806	171	-3958.5
191	0	0	0	5	59	-3202	-3192	-3166.5	-3186.83	179	-3959.83
192	33	34	35	45	1	2668.5	-7374	-7352	-4019.17	194	-3990.83
193	33	34	35	45	1	2554	-7447	-7433	-4108.67	197	-4019.17
194	1	1	2	9	0	-702.5	9322	9343.5	5987.667	7	-4055.67
195	33	34	35	45	32	-9225.5	-9228	-9170.5	-9208	242	-4062.83
196	3	6	5	26	9	7589.5	7564.5	7626	7593.333	3	-4108.67
197	1	2	7	28	0	-1963	-1916	-1899	-1926	139	-4184.83
198	5	33	2	16	36	-4655	5371	5387	2034.333	37	-4221
199	1	3	4	19	4	8485.5	-1557.5	-1542.5	1795.167	41	-4233
200	1	3	4	19	4	-1596	8426	8442.5	5090.833	15	-4323.67
201	0	0	0	0	15	-832.5	-781.5	-760	-791.333	101	-4329.17
202	3	10	11	22	7	-2658	7338	7359.5	4013.167	23	-4416.83
203	18	30	23	12	23	-5336	-5571.5	-5524	-5477.17	223	-4454.83
204	2	3	5	29	28	6637.5	-3378.5	-3360.5	-33.8333	88	-4490.33
205	2	5	7	25	0	8068.5	-1951	-1924.5	1397.667	44	-4514
206	3	0	0	34	63	-5080.5	4971.5	-5007	-1705.33	134	-4526.67
207	12	3	7	23	15	7127	-2960.5	-2946.5	406.6667	74	-4609.33
208	12	3	7	23	15	6947	-3015	-2993	313	79	-4696.83
209	32	1	14	13	63	-6215.5	3823	3838.5	482	71	-4720.67
210	32	1	14	13	63	3912	-6135.5	3911.5	562.6667	70	-4760.33
211	2	4	7	29	0	-2160	-2125.5	-2104.5	-2130	151	-4780
212	3	21	1	9	25	-3027.5	7021	-2962	343.8333	77	-4798.83
213	3	21	1	9	25	7010.5	-2962	-2940	369.5	76	-4899.5
214	0	0	0	10	58	6664.5	-3380	-3357.5	-24.3333	87	-4912.5
215	0	0	0	10	58	6665.5	-3371.5	-3349.5	-18.5	86	-4929.17
216	0	8	1	12	52	6414	-3629.5	-3607.5	-274.333	90	-4962.17
217	0	0	0	6	58	6892	-3182	-3162	182.6667	82	-5052.67
218	4	39	4	20	25	5468	-4574.5	-4557.5	-1221.33	114	-5157.17
219	4	39	4	20	25	5375	-4614	-4601	-1280	116	-5365.67
220	0	0	0	9	50	7113.5	-2930	-2908	425.1667	73	-5431
221	0	0	0	7	7	9366	-671	-649	2682	32	-5466.33
222	0	0	0	7	7	-717	-969.5	-917	-867.833	103	-5477.17
223	6	8	6	12	42	6364.5	-3694	-3675	-334.833	91	-5495.67
224	40	44	41	40	9	1311	-8713.5	-8694.5	-5365.67	220	-5527.33
225	1	0	0	17	58	6163	-3847	6213	2843	31	-5741.5
226	0	0	0	1	52	7453.5	-2620.5	-2604	743	60	-5895.17
227	4	0	1	40	63	4660	-5375.5	-5359	-2024.83	141	-5928.17
228	4	0	1	40	63	4725	-5360	4694.5	1353.167	47	-5954.5
229	0	0	0	8	55	6950	-3129	-3104.5	238.8333	80	-6186.83
230	29	2	18	18	54	4017	-6025	-6008	-2672	166	-6398.5
231	29	2	18	18	54	4005.5	-6040.5	4014.5	659.8333	66	-6565.67
232	2	14	1	10	31	7130	-2890	-2869	457	72	-6894
233	33	42	33	37	10	2235.5	-7756	-7730	-4416.83	203	-7188.5
234	33	42	33	37	10	2213.5	-7796	-7782	-4454.83	204	-7366.5

235	8	63	6	35	57	-8515	-8475.5	-8454.5	-8481.67	239	-7974.5
236	6	47	5	26	42	3780	3734	3785.5	3766.5	26	-8061.33
237	0	0	0	2	4	9720.5	-300.5	9752.5	6390.833	6	-8265.83
238	0	0	0	9	16	-1514.5	-1522.5	-1465.5	-1500.83	132	-8481.67
239	1	4	3	5	7	-1008	8989	9010.5	5663.833	13	-8560.83
240	18	28	21	22	24	-6534.5	4327	4349	713.8333	62	-8720.17
241	18	28	21	22	24	4187.5	-5670	-5658	-2380.17	162	-9208
242	2	0	1	21	42	-3308.5	-3297.5	6713.5	35.83333	84	-9293.33
243	63	0	63	63	63	-12878.5	-12582.5	-12565.5	-12675.5	248	-9463.67
244	33	0	32	48	63	-9714	1264.5	1319.5	-2376.67	161	-10384.7
245	7	1	4	6	18	-1996	8244.5	8298.5	4849	17	-10639.2
246	15	1	9	11	36	-4514	-3610	-3587.5	-3903.83	189	-12099.5
247	43	33	38	40	59	-10637.5	-10649.5	-10630.5	-10639.2	246	-12675.5
248	0	7	1	5	3	-780.5	9266.5	9321.5	5935.833	9	-12675.5
249	0	7	1	5	3	9283.5	-1072.5	9192	5801	10	-16220.3

Appendix 4: Experiment with 689 runs

Trials	A1	A2	A3	A4	A5	Scenario1	Scenario2	Scenario3	Total Fitness	rank	sorted
	Aircraft Number by Type					Fitness Value					
1	0	0	0	0	0	10014	-19.5	10030	6674.833	12	9342.167
2	63	63	63	63	63	-16017.5	-16027	-16000	-16014.8	689	8561
3	3	0	1	25	55	-4450	5866	5919	2445	112	8262
4	61	58	3	41	1	-8475.5	-8171.5	-8145.5	-8264.17	654	8094.167
5	8	62	5	34	56	-9152.5	-8301	-8293.5	-8582.33	660	8055.333
6	59	6	37	2	52	-7972.5	2234.5	2292	-1148.67	305	7209.833
7	38	59	59	61	13	-1632.5	-11505	-1459.5	-4865.67	578	7149.167
8	58	60	49	3	38	-395	-10441	-349.5	-3728.5	527	6939.667
9	20	13	55	63	10	2000.5	-8070	1979	-1363.5	327	6911
10	0	0	0	7	12	8915.5	-976.5	9078	5672.333	32	6875.833
11	3	0	1	32	63	-4963	5034.5	5057	1709.5	148	6803.833
12	14	3	10	1	22	7507	-2460	-2451	865.3333	185	6674.833
13	63	9	47	3	63	705.5	-9266	-9246	-5935.5	606	6372.833
14	2	4	6	27	1	8044.5	8034	8087.5	8055.333	5	6330.667
15	22	17	61	63	11	-8761	1273	1288.5	-2066.5	395	6223.333
16	19	20	16	1	13	6551	-3481.5	6577.5	3215.667	81	6209.167
17	39	40	33	2	25	2926.5	-6984.5	-6966	-3674.67	524	6202.667
18	61	62	56	33	51	-3169	-13185	-13164	-9839.33	670	6177.5
19	13	20	20	20	4	6131	6171	6220	6174	20	6175.167
20	25	39	39	41	9	-8552.5	-7686	-7668.5	-7969	649	6174
21	51	61	61	62	38	-3779	-13694.5	-13680.5	-10384.7	675	6032.333
22	11	10	13	1	0	-1929	8312.5	8358	4913.833	42	5984.167
23	43	42	45	33	32	358	-9788.5	-9766.5	-6399	620	5873.333
24	27	1	1	13	0	7915	-2122.5	7965.5	4586	52	5833
25	63	59	4	54	1	-9208	-9087.5	-9063	-9119.5	664	5824.333
26	2	17	0	13	8	-2013	-2041.5	8004	1316.5	164	5781.5
27	10	63	5	47	63	-9780.5	-9424	-9402	-9535.5	667	5725.5
28	21	21	21	21	21	-5424.5	4838	4882.5	1432	160	5701.333
29	42	42	42	42	42	-538.5	-10524	-10507.5	-7190	635	5688.5
30	22	2	13	17	54	4561.5	4621.5	4666.5	4616.5	51	5683.5
31	40	4	25	10	53	-7514	-6590	3466.5	-3545.83	515	5673.833
32	63	6	40	0	52	1792	-8045	2003	-1416.67	331	5672.333
33	61	6	38	1	52	-8071.5	-7911	2143	-4613.17	564	5646
34	5	3	21	33	47	4593	-5466	4594.5	1240.5	167	5576.333
35	1	0	0	17	63	5994.5	-4035	-4022	-687.5	274	5561
36	22	16	63	63	2	-8272	-8260	-8244.5	-8258.83	653	5249.667
37	13	12	6	16	53	-5171.5	-5037.5	5025	-1728	365	5124.833
38	0	0	0	34	57	5475	-4537.5	-4521	-1194.5	311	5124.333
39	63	63	54	0	36	-10771	-10767.5	-10744	-10760.8	679	5076.5
40	4	20	21	33	42	-6171.5	-6028.5	4023.5	-2725.5	457	5010
41	2	0	0	17	63	-5002.5	-4088	5962	-1042.83	300	4947.667
42	39	63	63	63	0	-1359.5	-11361	-11346.5	-8022.33	650	4913.833
43	5	6	1	27	47	5677	-4334.5	5707.5	2350	115	4872.667
44	1	0	1	23	63	-4740	-4377.5	-4356	-4491.17	562	4835.5
45	34	38	32	34	24	-8056	-8063	-8046.5	-8055.17	651	4780.5

46	22	24	1	31	31	4549	-5476	4575.5	1216.167	168	4769.333
47	0	0	1	19	63	5849	-4155	5900	2531.333	105	4738.167
48	63	63	3	47	0	-9064	-8761	-8740	-8855	662	4674.167
49	3	4	2	27	55	5404.5	-4588.5	5455.5	2090.5	126	4640.167
50	3	0	0	23	55	6063	-4023	-4000	-653.333	267	4622
51	8	63	6	36	56	-8730.5	-8420.5	-8399	-8516.67	659	4616.5
52	31	26	7	41	55	-8186	2038.5	2090.5	-1352.33	326	4586
53	0	0	0	9	55	6890.5	6842	6895	6875.833	10	4580.667
54	48	8	42	5	49	2467	-7570.5	-7553.5	-4219	550	4490.167
55	63	4	32	0	55	-7653.5	-7714	2347	-4340.17	556	4427.667
56	9	15	60	63	7	2167.5	-7713.5	2346.5	-1066.5	301	4333.833
57	59	11	41	2	51	-8382	-8229.5	1834.5	-4925.67	580	4268.833
58	59	1	33	2	53	2587.5	-7411.5	2647	-725.667	279	4259
59	58	63	53	3	37	-664	-10711	-651	-4008.67	542	4233.833
60	52	24	44	22	39	966	-9075	979	-2376.67	429	4227.167
61	45	41	52	41	26	-11164	-10274.5	-222.5	-7220.33	640	4208.167
62	0	63	63	63	0	577.5	-9484.5	606.5	-2766.83	462	4157.5
63	19	61	61	62	7	-10691.5	-10544.5	-10544	-10593.3	676	4138.167
64	63	0	0	0	63	-7214	-6337	3707	-3281.33	498	4130.5
65	61	3	19	1	58	-7284	-7091.5	2957	-3806.17	530	4128.167
66	53	18	36	6	43	2257	-7796	2251.5	-1095.83	303	4125.667
67	63	0	38	0	61	1767.5	-8124	1941.5	-1471.67	344	4118.667
68	26	44	31	36	23	2041.5	-8003.5	2046.5	-1305.17	322	3988.833
69	59	22	21	14	37	2392	-7679	2375.5	-970.5	296	3907.667
70	59	0	53	0	63	1249	-8772.5	1281.5	-2080.67	399	3781
71	61	63	0	53	0	1017.5	1179.5	1240.5	1145.833	172	3752.5
72	42	25	26	13	53	2093.5	-7996	2054.5	-1282.67	319	3711
73	25	43	16	23	55	1771	-8115.5	1931.5	-1471	343	3694.833
74	7	63	4	35	56	1816.5	1789	1833	1812.833	143	3653.5
75	8	63	5	34	56	-8474.5	1740	1792	-1647.5	354	3564.333
76	62	3	39	0	52	-8714	2234	2286.5	-1397.83	328	3491.833
77	61	4	38	1	52	-8702.5	-7815.5	2240.5	-4759.17	571	3483.667
78	60	20	39	28	55	-11002.5	-10115.5	-54.5	-7057.5	633	3261.833
79	58	0	35	0	49	2971.5	2926	2973	2956.833	91	3258.167
80	33	29	53	43	19	1223	-8860.5	1194	-2147.83	410	3230.167
81	45	44	51	23	29	-9771.5	-9628	420.5	-6326.33	618	3215.667
82	63	63	0	0	63	421	-9475.5	564.5	-2830	466	3193.5
83	61	62	25	2	51	-53	-18.5	30.5	-13.6667	221	3193
84	0	0	63	63	0	-7202.5	-6304.5	3734	-3257.67	496	3156.667
85	10	7	59	63	5	-7371.5	-7232	-7212.5	-7272	641	3155.5
86	26	28	56	62	11	703	-9177	-9164.5	-5879.5	602	3137
87	32	44	58	62	12	-402.5	-10436	-339.5	-3726	526	3105.333
88	63	63	63	0	63	-2539.5	-12631	-2541.5	-5904	605	3094.333
89	51	61	61	31	38	-12279	-2068.5	-2018.5	-5455.33	592	3026.667
90	0	0	0	63	0	-3329	6869.5	6910.5	3483.667	77	2975.5
91	10	7	28	63	5	-6564	4324	4341.5	700.5	191	2956.833
92	24	19	47	53	17	1991.5	-8023.5	-8007	-4679.67	567	2898.833
93	28	26	40	42	25	-8221.5	-8075.5	1978	-4773	572	2885.833
94	44	52	8	0	55	2078	-7975	2077.5	-1273.17	316	2884.333
95	38	42	20	16	43	2087	-7960	2090	-1261	315	2873.667

96	34	28	38	56	7	1890	-8173	1882	-1467	341	2866.333
97	47	43	20	48	4	-8271.5	-8141.5	1913	-4833.33	577	2848.5
98	63	63	0	0	0	-6479	-6345.5	3713.5	-3037	481	2835.833
99	62	61	2	21	1	2611.5	-7405.5	-7392	-4062	545	2832.667
100	0	0	63	63	63	-9621.5	-9507	-9494.5	-9541	668	2744.5
101	10	7	59	63	37	-8844.5	1298.5	1313.5	-2077.5	398	2700.833
102	16	29	38	53	25	2002	1989.5	2042.5	2011.333	132	2568.167
103	12	46	22	44	41	1802	-8275	1782.5	-1563.5	349	2565.833
104	0	63	0	0	63	3732.5	3738	3787	3752.5	71	2555.5
105	4	63	3	17	60	2692.5	-7343.5	2714.5	-645.5	266	2531.333
106	63	0	63	63	0	-9630	-9457.5	597.5	-6163.33	613	2517
107	42	7	59	63	5	1067.5	-8845.5	1205	-2191	414	2499.833
108	34	30	58	63	28	-645	-10688.5	-635.5	-3989.67	541	2488.167
109	49	46	60	63	45	-3135.5	-3134.5	-3089.5	-3119.83	485	2485.833
110	12	4	53	63	0	-6779	3468.5	3510	66.5	217	2468.167
111	16	8	54	63	5	2810	-7329.5	-7316.5	-3945.33	539	2467.167
112	48	60	51	29	36	-12114	-11220	-1171	-8168.33	652	2445
113	63	60	47	0	40	-480	-10525	-435	-3813.33	531	2435.833
114	28	59	61	63	11	-1035	-11124	-1070	-4409.67	560	2369.667
115	49	51	43	13	36	-9771.5	-9636	457	-6316.83	617	2350
116	41	41	38	22	34	1257	-8820	1217.5	-2115.17	404	2317
117	16	16	16	48	16	4417.5	-5631	4417	1067.833	178	2311.167
118	61	62	56	2	51	-1616	-11611.5	-11597.5	-8275	655	2269.167
119	59	59	43	6	30	134	-9859.5	184.5	-3180.33	489	2256.333
120	57	61	55	0	46	-1082.5	-10980.5	-10969	-7677.33	647	2219.5
121	62	57	0	44	0	-9064	-8164.5	1880.5	-5116	583	2215.667
122	35	60	33	5	39	1353.5	-8647.5	-8638.5	-5310.83	590	2154
123	63	60	63	1	37	-1179.5	-11221	-1174.5	-4525	563	2141.333
124	0	62	0	36	57	-8652.5	-7774	2279.5	-4715.67	568	2108.5
125	58	60	51	32	49	-2426	-2458.5	-2405	-2429.83	434	2104
126	58	60	47	0	27	495	421	460	458.6667	200	2090.5
127	35	58	49	47	17	-432.5	-10333	-10321.5	-7029	632	2075.167
128	41	60	63	63	9	-11821.5	-11832.5	-1742	-8465.33	658	2074.5
129	29	31	22	18	36	3067.5	-6837.5	3250	-173.333	232	2046.833
130	48	59	40	53	13	-11564	-10668	-612	-7614.67	645	2030.833
131	28	59	63	63	13	-1305.5	-11334.5	-1248.5	-4629.5	565	2024.833
132	63	58	0	33	1	2244.5	-7780.5	2302.5	-1077.83	302	2011.333
133	29	59	41	51	14	246.5	-9752.5	-9746.5	-6417.5	621	2000.833
134	47	59	63	63	12	-12371.5	-12228.5	-2185.5	-8928.5	663	1969
135	0	62	0	24	57	2856	2859	2906	2873.667	95	1954.167
136	46	60	60	62	30	-13814	-12900	-2849.5	-9854.5	671	1951.167
137	55	62	62	62	46	-4299.5	-4338	-4293	-4310.17	552	1950.5
138	19	30	30	31	7	4207	4213.5	4261	4227.167	60	1914.167
139	42	41	22	35	22	-9014	-8130	-8114	-8419.33	657	1856
140	51	49	13	38	11	-8114	-8137.5	1923.5	-4776	573	1847.333
141	63	63	0	63	0	573.5	-9491.5	560	-2786	464	1838.333
142	62	61	2	52	1	-9071.5	-8939.5	1097.5	-5637.83	597	1826.167
143	0	0	63	0	63	3697.5	-6345.5	3704.5	352.1667	204	1812.833
144	16	16	48	16	48	2759.5	-7185.5	2873.5	-517.5	256	1800.667
145	31	36	32	32	37	1673.5	-8400	1648.5	-1692.67	361	1754.5

146	33	28	32	32	27	-7790.5	-7619.5	2423.5	-4328.83	554	1747.167
147	7	63	5	34	61	1533.5	-8530	1530.5	-1822	375	1716.167
148	47	40	46	47	47	-1266	-1309	-1258	-1277.67	317	1709.5
149	17	24	18	17	17	-4829	5371	5460.5	2000.833	133	1689.833
150	43	59	4	39	19	1773	-8227.5	-8209	-4887.83	579	1651.5
151	26	61	4	36	38	-8421.5	-8278	1769	-4976.83	581	1642.5
152	0	63	63	0	63	569	569	623.5	587.1667	196	1636.833
153	4	63	34	17	60	-9802.5	-8903.5	1142.5	-5854.5	600	1601
154	62	58	3	41	0	1846.5	1832.5	1889	1856	139	1510
155	62	60	23	48	22	-11652.5	-10801	-10794	-11082.5	683	1505.667
156	62	61	43	56	42	-13244	-13231.5	-3145.5	-9873.67	672	1486.833
157	31	29	2	21	1	-4371.5	5864	5909	2467.167	111	1473.667
158	27	62	16	41	58	-334	-10245.5	-10230.5	-6936.67	631	1456.333
159	0	62	0	27	54	-7321.5	2918	2971	-477.5	252	1434.833
160	0	62	0	27	54	2911.5	-7151	2900	-446.5	248	1432
161	2	4	8	32	0	-3214	-2313	-2296.5	-2607.83	445	1393.167
162	0	0	0	4	63	-3413.5	6619	-3360	-51.5	224	1357.5
163	0	0	0	4	63	-3613	-3319	-3297.5	-3409.83	511	1347.833
164	2	3	5	20	1	-2423	-1553.5	-1532.5	-1836.33	378	1316.5
165	2	5	7	34	1	-3335	7518.5	7539.5	3907.667	69	1253.667
166	2	2	3	12	1	-1914	-1033	-1007	-1318	324	1240.667
167	4	6	9	27	1	-3227.5	-2623.5	-2571	-2807.33	465	1240.5
168	0	2	3	27	1	-1741	-1682.5	-1660.5	-1694.67	362	1216.167
169	15	22	23	20	4	-5102.5	5771	5793.5	2154	122	1185.667
170	6	7	13	27	1	7220	-2740	-2721.5	586.1667	197	1167
171	2	3	5	25	6	-2071.5	-2084	-2057	-2070.83	396	1149
172	2	5	7	29	0	-3035	7826.5	-2152.5	879.6667	184	1145.833
173	0	0	0	5	17	-1435.5	8870	-1109	2108.5	124	1118
174	4	6	7	25	1	-2228	7841	7857.5	4490.167	54	1094.667
175	0	2	5	29	1	8157.5	-1879	-1857.5	1473.667	157	1094.333
176	13	12	14	0	0	-2039.5	8023	8039	4674.167	48	1093
177	3	3	9	26	2	-2304	-2188	-2170	-2220.67	418	1083.5
178	1	5	3	28	0	-2188.5	8120.5	-1859.5	1357.5	162	1067.833
179	23	1	16	16	55	-6464	4420.5	4436.5	797.6667	188	1030.667
180	10	4	4	22	1	7936.5	-2036	8020	4640.167	49	1013
181	0	4	8	32	1	7820	-2281.5	-2259.5	1093	176	991
182	35	1	0	8	0	-2209.5	7771	-2207.5	1118	173	983
183	6	16	9	28	3	-3107.5	-3144	-3122	-3124.5	486	907.6667
184	0	0	3	26	0	-1472	-1483.5	-1461.5	-1472.33	345	879.6667
185	23	42	33	32	9	-7224	-7220.5	-7173	-7205.83	636	865.3333
186	1	24	4	18	22	6421	-3494	-3476	-183	233	849.6667
187	1	43	2	9	42	-5764	-4870	-4839	-5157.67	586	836.1667
188	2	3	6	27	0	-2077	-1903.5	-1880.5	-1953.67	391	797.6667
189	0	0	0	6	37	-3035	7819.5	7840	4208.167	61	747.3333
190	0	0	0	3	18	-1313	-1036.5	-1020	-1123.17	304	738.3333
191	0	0	0	63	63	-6303.5	3691.5	3708	365.3333	203	700.5
192	0	0	0	36	59	5258	-4700.5	5349.5	1969	134	699.3333
193	4	7	7	13	38	6672	-3413.5	-3394	-45.1667	223	698.5
194	9	13	13	16	21	-3544	-3597	-3571	-3570.67	516	654
195	63	63	63	63	0	-12571	-12618.5	-12598.5	-12596	685	637.1667

196	63	63	63	63	0	-2623	-12634	-2601.5	-5952.83	608	587.1667
197	0	0	0	0	63	6717.5	-3197.5	-3188	110.6667	214	586.1667
198	0	0	0	5	59	6754.5	-3172.5	-3150.5	143.8333	213	558.1667
199	0	0	0	9	42	7519.5	-2514	-2497	836.1667	187	492.3333
200	0	0	0	9	63	-3589	-3578.5	-3561.5	-3576.33	517	458.6667
201	0	0	0	7	0	-311.5	-311.5	-300	-307.667	243	450.3333
202	5	3	4	6	41	-3216.5	-3225	-3198	-3213.17	493	428.3333
203	0	0	0	12	63	-4430	-3741.5	-3720	-3963.83	540	365.3333
204	16	13	17	0	0	-3184	-2268	-2246.5	-2566.17	443	352.1667
205	2	1	5	13	55	-3964	-3843.5	-3822.5	-3876.67	536	280.1667
206	0	0	0	5	55	-3593	-2978.5	-2953	-3174.83	488	269.6667
207	24	3	18	21	54	4069	-5973.5	-5951.5	-2618.67	448	252.8333
208	0	0	0	10	31	-2218	-2033.5	8012.5	1253.667	165	252.5
209	0	0	0	8	63	-3813	-3547.5	-3520.5	-3627	520	242.3333
210	27	1	1	14	0	-2146.5	-2116	-2094.5	-2119	405	230.8333
211	9	11	3	17	42	-4044.5	-4137.5	-4113.5	-4098.5	547	163.5
212	0	0	0	1	63	-3546	-3187	-3173	-3302	501	158.8333
213	28	41	33	39	0	-7316.5	-7017.5	-7001	-7111.67	634	143.8333
214	0	1	0	8	58	6602	-3394	-3387	-59.6667	226	110.6667
215	0	0	0	10	52	6852	-3071	-3054	242.3333	209	91.16667
216	4	6	7	1	0	-1802.5	-875.5	-848.5	-1175.5	309	76.66667
217	17	26	27	21	4	-5652.5	5217.5	5238	1601	153	66.5
218	17	26	27	21	4	5238	-4794	-4772.5	-1442.83	334	43.5
219	0	0	0	2	1	-290	-188.5	-165.5	-214.667	239	33
220	0	0	0	9	13	-2014	-1378	-1345.5	-1579.17	352	8.833333
221	5	1	2	0	0	-664	9584	9605.5	6175.167	19	-13.6667
222	16	11	15	1	0	-2439.5	-2426	-2373	-2412.83	433	-41.1667
223	7	1	4	6	18	-2714	-1841.5	-1823.5	-2126.33	407	-45.1667
224	15	1	9	11	36	-3623.5	-3615	-3587.5	-3608.67	519	-51.5
225	43	33	38	40	59	-10637.5	-10649.5	-10630.5	-10639.2	677	-53
226	10	0	0	5	0	9333.5	9321.5	9371.5	9342.167	1	-59.6667
227	37	1	1	18	0	-2918.5	7120	7141.5	3781	70	-118.667
228	6	3	11	3	1	8686	-1242	-1218.5	2075.167	127	-126.5
229	25	33	41	34	8	-7952.5	-7086.5	-7060.5	-7366.5	643	-142.5
230	0	21	0	0	21	-2110.5	-2139.5	-2131	-2127	408	-144.667
231	0	42	0	0	42	-4583.5	-4210.5	-4196.5	-4330.17	555	-169.167
232	9	13	13	16	7	-2896.5	-2902	-2883	-2893.83	470	-173.333
233	4	7	7	11	9	8018	-1932.5	-1906	1393.167	161	-183
234	12	19	20	14	3	-4061.5	-3420	-3402	-3627.83	521	-190.5
235	14	21	20	26	5	-4473	-4343	-4318	-4378	558	-192.5
236	10	9	13	0	0	-1788.5	-1633.5	-1619.5	-1680.5	360	-196.833
237	14	17	19	19	26	-4890	-4791.5	-4764.5	-4815.33	576	-203.5
238	12	23	21	21	0	-4021.5	-3860.5	-3840.5	-3907.5	537	-208.667
239	12	23	21	21	0	-3840.5	-3889	-3867	-3865.5	535	-214.667
240	18	14	14	18	3	-3367	-3325.5	6719	8.833333	220	-217.167
241	22	7	7	15	1	-2991.5	-2637.5	-2617	-2748.67	460	-263.833
242	63	0	0	0	0	-3299.5	-3187	-3165	-3217.17	495	-302
243	45	1	1	7	0	-3602.5	-2753.5	-2736	-3030.67	480	-307.667
244	0	63	63	63	63	-13502.5	-12648.5	-12625	-12925.3	686	-309.333
245	7	42	42	42	34	1737	1730.5	1774	1747.167	146	-357.167

246	15	23	23	24	5	5624	-4516.5	5539.5	2215.667	121	-361
247	15	23	23	24	5	5432	-4526	-4524	-1206	312	-410.333
248	41	47	47	47	35	-10874	-10880.5	-10863.5	-10872.7	681	-446.5
249	7	10	10	10	2	8100	8070	8112.5	8094.167	4	-459.833
250	12	35	11	10	12	-4902.5	-4035	-4012	-4316.5	553	-464.667
251	14	5	29	30	0	6031.5	-3935.5	-3917.5	-607.167	261	-466.167
252	1	2	4	5	11	-1313	-1185	-1158.5	-1218.83	313	-477.5
253	7	1	4	10	26	-2408.5	7584.5	7601	4259	58	-485.333
254	15	1	9	14	40	6051	-3945	-3930.5	-608.167	262	-509
255	0	0	0	4	6	-1402.5	-496.5	-472	-790.333	283	-511.667
256	9	0	0	9	8	-2184	-1568	-1516	-1756	367	-517.5
257	18	1	1	11	4	-1966	8231	-1748	1505.667	155	-556.833
258	45	32	32	38	0	-7348	-7381	-7354.5	-7361.17	642	-561
259	0	0	0	4	38	-3014	-2146.5	-2134.5	-2431.67	435	-567.167
260	2	13	8	12	11	-2287.5	-2290.5	-2264	-2280.67	421	-577
261	0	0	0	2	13	-1378	-769.5	-747	-964.833	294	-607.167
262	0	21	0	5	29	-3363.5	7237	7259.5	3711	72	-608.167
263	0	42	0	2	46	5509.5	-4511	-4485	-1162.17	307	-611.833
264	16	7	13	4	25	-3421.5	-3253.5	-3231	-3302	501	-618.667
265	6	13	13	0	0	-1753	-1619	-1599.5	-1657.17	357	-636.167
266	15	6	12	3	0	-2702.5	-1836.5	-1819	-2119.33	406	-645.5
267	7	14	14	0	0	-1890	-1788.5	-1761.5	-1813.33	373	-653.333
268	11	13	20	11	1	-3181.5	-2844.5	-2816.5	-2947.5	473	-659.5
269	11	7	6	0	0	-1593.5	-1244.5	-1217.5	-1351.83	325	-662.5
270	7	28	9	1	21	-3415.5	-3336.5	-3315	-3355.67	507	-663.667
271	4	45	4	0	42	5200.5	-4770	-4759.5	-1443	335	-665.5
272	37	5	38	32	0	-5793	-5602.5	-5587	-5660.83	598	-667.333
273	22	2	8	17	53	-5287.5	-5141.5	-5126	-5185	587	-670.167
274	22	2	18	17	55	-6614	-5683	4373	-2641.33	451	-687.5
275	21	11	19	22	38	4523	-5536.5	4514.5	1167	170	-704.667
276	20	21	24	26	23	4300.5	-5705	4353.5	983	182	-712.5
277	10	47	47	47	4	2303.5	-7770.5	-7752.5	-4406.5	559	-714
278	22	0	12	16	57	-5352.5	-5387.5	-5384	-5374.67	591	-716.5
279	22	1	12	17	56	-5560	-5383	4669	-2091.33	400	-725.667
280	19	26	10	13	55	-6291.5	-6138.5	3918.5	-2837.17	468	-729.167
281	25	0	16	21	53	-5937.5	-5739	4311.5	-2455	437	-752
282	24	11	11	19	2	-3508.5	-3333	6718	-41.1667	222	-786.167
283	22	20	20	25	5	-4773	-4643	-4613.5	-4676.5	566	-790.333
284	10	47	47	47	35	579.5	-9338	-9321.5	-6026.67	609	-793.833
285	16	31	1	11	27	5566	5725	5774.5	5688.5	29	-809.333
286	38	0	1	15	0	7374.5	-2716	-2696.5	654	194	-816.667
287	13	41	20	21	26	3948	-6096.5	-6068	-2738.83	459	-850.667
288	6	52	10	10	44	-6118	-6116	-6104	-6112.67	610	-863.333
289	21	26	34	35	0	-5978	-5803	-5790.5	-5857.17	601	-877.167
290	20	28	32	33	4	4091.5	-5888.5	-5873.5	-2556.83	441	-897.167
291	10	2	1	5	1	-1035.5	9018.5	9038.5	5673.833	31	-906.667
292	10	3	2	6	1	-1229	-1137	-1110	-1158.67	306	-951
293	8	0	1	6	0	-841.5	9220.5	9241	5873.333	23	-962.833
294	8	0	1	6	0	-809.5	-1025.5	9239.5	2468.167	110	-964.833
295	0	4	7	28	1	-2089.5	7967.5	7988	4622	50	-965.833

296	6	1	3	6	1	-918.5	9124	9139	5781.5	26	-970.5
297	6	1	3	6	1	-906.5	-1125	9140.5	2369.667	114	-973.333
298	11	0	0	4	0	-814.5	9227.5	-746.5	2555.5	104	-974.333
299	0	0	0	10	63	-3732	6319	6339.5	2975.5	90	-1016.17
300	7	0	0	7	18	8509.5	-1567	-1540.5	1800.667	144	-1042.83
301	9	0	0	4	0	-687	-661.5	-639	-662.5	269	-1066.5
302	9	0	0	4	0	-713	9321.5	9344	5984.167	22	-1077.83
303	10	0	1	5	0	-883.5	9168	9188.5	5824.333	25	-1095.83
304	5	1	3	0	0	-527.5	9519.5	9540.5	6177.5	18	-1123.17
305	5	1	3	0	0	-507.5	-727.5	-673.5	-636.167	265	-1148.67
306	12	13	13	15	3	-2920	-2835.5	-2812	-2855.83	469	-1158.67
307	19	63	63	52	13	-598.5	-10536.5	-10514.5	-7216.5	639	-1162.17
308	19	63	63	52	13	-506.5	-10528.5	-490	-3841.67	533	-1173.5
309	5	0	0	3	0	9560.5	-439	-425	2898.833	92	-1175.5
310	11	1	0	8	10	-1793	-1775	-1722	-1763.33	369	-1186.67
311	9	0	0	2	0	-615	-569	-547	-577	260	-1194.5
312	17	32	1	14	37	-5112.5	-5325	4940	-1832.5	377	-1206
313	17	32	1	14	37	4975	-5061	-5048	-1711.33	364	-1218.83
314	10	0	0	6	0	-900.5	-836	-815.5	-850.667	287	-1250.33
315	11	15	18	0	0	-2277	7769.5	7790.5	4427.667	55	-1261
316	6	10	10	14	2	-2262	-2140	-2119.5	-2173.83	412	-1273.17
317	8	10	10	6	2	-1915	-1830.5	-1812.5	-1852.67	379	-1277.67
318	8	10	10	6	2	-1925.5	-1835	-1816.5	-1859	381	-1282.5
319	4	9	9	18	1	-2119	7923	7938	4580.667	53	-1282.67
320	6	7	9	10	11	-2255.5	-2189	-2160	-2201.5	416	-1290.67
321	8	13	11	10	0	-2191.5	-2117	-2095.5	-2134.67	409	-1294.5
322	5	4	8	9	20	-2435	-2340	-2313	-2362.67	427	-1305.17
323	5	4	8	9	20	-2360	-2310	-2289.5	-2319.83	422	-1314.5
324	5	6	8	7	1	-1444.5	-1388.5	-1367.5	-1400.17	330	-1318
325	6	7	7	7	1	-1538	-1435.5	-1415	-1462.83	340	-1351.83
326	6	7	7	7	1	-1500	-1431	-1414	-1448.33	336	-1352.33
327	3	1	1	0	0	-339	9718.5	9739	6372.833	13	-1363.5
328	3	1	1	0	0	-533.5	-527	-474.5	-511.667	255	-1397.83
329	9	13	13	13	3	7480	-2584.5	7519	4138.167	63	-1398.67
330	11	17	17	17	3	-3387.5	-3285	-3270	-3314.17	503	-1400.17
331	39	63	63	63	13	-2161.5	-12089	-12068.5	-8773	661	-1416.67
332	26	42	42	42	8	2010.5	2008.5	2055.5	2024.833	131	-1421.83
333	4	5	5	5	1	8962.5	-1042	9017.5	5646	33	-1430.83
334	10	19	6	10	5	-2582	7469.5	7489.5	4125.667	66	-1442.83
335	10	19	6	10	5	-2642	-2538	-2516	-2565.33	442	-1443
336	4	1	14	10	0	-1538.5	8518.5	-1465	1838.333	141	-1448.33
337	19	40	0	11	30	4996	-5020.5	-5005.5	-1676.67	359	-1449.83
338	2	3	3	8	9	-1337.5	-1281	-1253.5	-1290.67	320	-1451.33
339	35	37	37	37	1	-7391.5	2631	2646.5	-704.667	275	-1451.67
340	9	10	11	9	2	7901	-2095.5	-2083.5	1240.667	166	-1462.83
341	5	10	9	11	2	-1985	-1887	-1860	-1910.67	386	-1467
342	5	10	9	11	2	-1961	-1883	-1864.5	-1902.83	383	-1467.67
343	13	10	14	0	0	-2002.5	-1891	-1872	-1921.83	388	-1471
344	1	5	8	33	1	-2459.5	7572.5	7588.5	4233.833	59	-1471.67
345	1	5	8	33	1	-2479	-2432	-2406	-2439	436	-1472.33

346	6	0	0	0	0	-357.5	-576	-522.5	-485.333	253	-1475.67
347	11	22	3	16	18	6434	-3523	-3501.5	-196.833	236	-1511.83
348	40	47	1	6	45	3025.5	-6968	-6949.5	-3630.67	522	-1551
349	1	2	35	45	1	5829	-4216.5	5845	2485.833	109	-1563.5
350	2	0	1	6	37	7619.5	-2334.5	-2312	991	181	-1570.33
351	3	1	1	3	18	-1295.5	-1289	-1263	-1282.5	318	-1572.83
352	63	63	63	0	0	418.5	-9505.5	-9496	-6194.33	614	-1579.17
353	8	4	0	9	41	6768.5	-3156	-3136	158.8333	212	-1601
354	8	4	0	9	41	6913.5	-3085.5	-3069.5	252.8333	207	-1647.5
355	2	0	0	0	0	9837	-139	-117.5	3193.5	82	-1649.67
356	5	4	0	1	1	-823	-829.5	-797.5	-816.667	286	-1655.67
357	7	8	5	4	0	-1261.5	-1474	-1208	-1314.5	323	-1657.17
358	7	8	5	4	0	-1300	-1236	-1215	-1250.33	314	-1661.5
359	3	0	0	0	0	-431	-426	-374	-410.333	247	-1676.67
360	9	13	2	1	13	-2008.5	-1918.5	-1899	-1942	390	-1680.5
361	3	1	2	3	5	-971.5	-979	-947	-965.833	295	-1692.67
362	3	1	2	3	5	-738	-973.5	-920	-877.167	289	-1694.67
363	7	4	7	0	0	-962	-1179	-907.5	-1016.17	299	-1705.5
364	14	24	14	17	12	-4147	5915.5	5936	2568.167	102	-1711.33
365	14	24	14	17	12	5889	-4080	-4065	-752	281	-1728
366	15	27	7	14	19	5876.5	-4127.5	-4107.5	-786.167	282	-1753
367	15	22	1	9	23	6469.5	-3531	-3516	-192.5	235	-1756
368	17	40	1	13	31	4877	-5119	-5100	-1780.67	372	-1758.67
369	17	40	1	13	31	4902	-5115.5	-5099	-1770.83	370	-1763.33
370	14	26	1	11	17	6509.5	-3478	-3459	-142.5	229	-1770.83
371	8	0	1	5	0	-764	-975	9290	2517	106	-1771.17
372	3	1	4	0	0	-485	9567.5	9587.5	6223.333	15	-1780.67
373	3	1	4	0	0	-694	-675	-622	-663.667	270	-1813.33
374	10	0	32	5	0	7507.5	-2404.5	-2380	907.6667	183	-1817.17
375	7	6	7	9	1	-1649	-1543.5	-1518.5	-1570.33	350	-1822
376	7	6	7	9	1	-1601	-1537	-1515	-1551	348	-1822.17
377	5	0	0	0	0	-384	-281.5	-262.5	-309.333	244	-1832.5
378	8	7	7	9	1	-1891	-1874.5	-1821.5	-1862.33	382	-1836.33
379	8	7	7	9	1	-1705	-1636	-1608	-1649.67	355	-1852.67
380	4	37	37	37	33	-7491	2569.5	-7410	-4110.5	548	-1857.83
381	8	8	10	10	1	8179	-1860.5	8188	4835.5	44	-1859
382	8	8	10	10	1	-1969.5	-1890	-1861.5	-1907	384	-1862.33
383	11	0	1	5	0	-976.5	-885.5	-858	-906.667	291	-1902.83
384	3	3	5	18	1	-1584	8468.5	8488.5	5124.333	38	-1907
385	4	2	4	9	0	-1011	9023	9038.5	5683.5	30	-1908.17
386	4	2	4	9	0	-1006.5	-1225.5	9039.5	2269.167	118	-1910.67
387	1	34	35	45	32	-7511	-7392	-7363.5	-7422.17	644	-1914.33
388	1	34	35	45	32	2675.5	-7352	2698	-659.5	268	-1921.83
389	0	6	9	34	1	-2572.5	7471	7486	4128.167	65	-1924.83
390	0	6	9	34	1	-2578	-2535	-2508.5	-2540.5	438	-1942
391	6	3	5	18	1	-1749.5	8319.5	-1659.5	1636.833	152	-1953.67
392	6	3	5	18	1	-1731	8318.5	-1660	1642.5	151	-1962.17
393	0	5	7	36	1	-2520	7524	-2455	849.6667	186	-1965
394	1	0	1	5	30	-1944	8116	8136	4769.333	46	-1986.5
395	0	0	0	13	63	-3801.5	-3796	-3774	-3790.5	529	-2066.5

396	6	1	4	0	0	9561	-518.5	-497	2848.5	97	-2070.83
397	6	1	4	0	0	-614	-824.5	-558	-665.5	271	-2071
398	37	0	0	3	0	-2006	-1987.5	-1966	-1986.5	394	-2077.5
399	15	0	1	5	0	8991.5	-1044.5	-1013.5	2311.167	117	-2080.67
400	2	0	1	0	0	-250	9818	-157	3137	86	-2091.33
401	4	0	0	2	0	-574	-580	-547.5	-567.167	259	-2096.5
402	4	0	0	2	0	-584.5	-578	-520.5	-561	258	-2101.33
403	7	0	1	3	0	-832	-826.5	-769.5	-809.333	285	-2102.33
404	37	0	32	34	0	-5209	-5428.5	-5157	-5264.83	589	-2115.17
405	6	3	4	3	0	9123	-838.5	-820	2488.167	108	-2119
406	4	0	2	0	0	-369	9670	9691	6330.667	14	-2119.33
407	8	1	2	1	0	-890	-879	-821	-863.333	288	-2126.33
408	2	1	4	0	0	-416.5	-625	9640.5	2866.333	96	-2127
409	2	1	4	0	0	-636.5	-628.5	-570.5	-611.833	263	-2134.67
410	7	1	2	2	0	-662	-879	-608.5	-716.5	278	-2147.83
411	8	0	2	3	0	-717	-925.5	9340	2565.833	103	-2151.67
412	5	1	2	1	0	-739	-728	-670.5	-712.5	276	-2173.83
413	13	24	26	26	5	5193	-4742.5	-4716	-1421.83	332	-2183.5
414	12	13	14	15	3	7035.5	-2881	-2869.5	428.3333	202	-2191
415	5	0	1	3	0	9451	-487.5	-465.5	2832.667	99	-2198.17
416	5	0	1	3	0	-744	-725.5	-672.5	-714	277	-2201.5
417	11	0	0	7	0	-963	-1175.5	9089.5	2317	116	-2205.17
418	11	0	0	7	0	-979.5	9068	9088	5725.5	27	-2220.67
419	7	5	8	7	1	-1687	-1677.5	-1620	-1661.5	358	-2250.33
420	7	15	12	13	3	-2599	-2535.5	-2514	-2549.5	440	-2262.83
421	4	0	0	0	0	-335	-237.5	-219	-263.833	241	-2280.67
422	2	3	6	22	1	-1988.5	-1977.5	-1920.5	-1962.17	392	-2319.83
423	2	5	6	32	1	-2358	7672	7687.5	4333.833	56	-2322.67
424	0	0	1	8	35	-2276	7769.5	-2209.5	1094.667	174	-2341
425	0	0	1	8	35	-2192	-2192.5	-2166	-2183.5	413	-2343.17
426	1	0	1	0	0	-386	-375	-322	-361	246	-2358.33
427	63	63	2	0	0	-6670.5	-6678	-6651	-6666.5	626	-2362.67
428	34	32	2	0	0	6468.5	-3455.5	-3447	-144.667	230	-2367
429	0	0	2	0	0	9760	-154.5	-135.5	3156.667	84	-2376.67
430	2	0	2	0	0	-469	-478.5	-446.5	-464.667	250	-2398.67
431	2	0	2	0	0	-480	-476	-423.5	-459.833	249	-2407.5
432	10	13	14	13	3	-2757.5	-2684.5	-2662	-2701.33	455	-2410.5
433	5	0	2	1	0	-544	-438	-416.5	-466.167	251	-2412.83
434	57	57	53	49	63	-14243	-14226	-14172.5	-14213.8	687	-2429.83
435	57	57	53	49	63	-3864.5	-3881	-3834.5	-3860	534	-2431.67
436	46	52	14	50	6	1530	-8446.5	-8437.5	-5118	584	-2439
437	24	62	7	14	55	1874.5	-8141.5	1912	-1451.67	339	-2455
438	24	62	7	14	55	1940.5	1933	1980	1951.167	136	-2540.5
439	57	12	32	18	44	1888	-8171.5	1880.5	-1467.67	342	-2544.67
440	4	19	45	6	39	4382	-5672.5	4382.5	1030.667	179	-2549.5
441	6	31	38	31	21	3599	-6379.5	-6354.5	-3045	482	-2556.83
442	3	51	63	48	35	-26	-10017	-10002.5	-6681.83	629	-2565.33
443	4	48	60	46	34	451	423	477	450.3333	201	-2566.17
444	4	48	60	46	34	446	-9617	474	-2899	471	-2568.33
445	6	13	30	6	26	-4156	-4065.5	-4052	-4091.17	546	-2607.83

446	6	13	30	6	26	5927.5	-4065	-4050	-729.167	280	-2608.67
447	10	1	2	8	15	8270.5	8231	8284.5	8262	3	-2610.33
448	10	1	2	8	15	-1862	-1813.5	-1791	-1822.17	376	-2618.67
449	10	0	0	2	0	-667	9371	9393	6032.333	21	-2621
450	26	4	11	9	15	6796	6781.5	6834	6803.833	11	-2633.83
451	41	8	21	14	29	4263	-5678.5	-5659.5	-2358.33	426	-2641.33
452	41	8	21	14	29	4357	-5668.5	-5656.5	-2322.67	423	-2652.17
453	60	38	48	41	54	-1970.5	-1986.5	-1938	-1965	393	-2666.5
454	21	21	22	3	2	6403.5	-3497	-3478	-190.5	234	-2671.67
455	17	4	1	18	2	7835.5	-2146.5	-2132	1185.667	169	-2701.33
456	17	4	1	18	2	-2214	-2135.5	-2105.5	-2151.67	411	-2714.17
457	53	56	15	63	8	242	-9777.5	305.5	-3076.67	483	-2725.5
458	31	15	2	26	8	5861	-4128.5	-4114	-793.833	284	-2738.5
459	63	63	55	63	63	-5265.5	-5284	-5231	-5260.17	588	-2738.83
460	5	34	41	33	22	3208	-6776.5	-6758.5	-3442.33	512	-2748.67
461	2	55	60	54	48	-957.5	-10969	-10954	-7626.83	646	-2754.83
462	7	8	7	8	0	8576.5	8530	8576.5	8561	2	-2766.83
463	7	9	8	9	1	-1810	-1736	-1713	-1753	366	-2784
464	6	13	21	8	18	-3412.5	-3333.5	-3309.5	-3351.83	506	-2786
465	8	7	0	12	0	8575.5	-1372	-1352	1950.5	137	-2807.33
466	3	22	56	4	55	-7092	2966.5	-7013.5	-3713	525	-2830
467	3	22	56	4	55	3026	-6989	3057	-302	242	-2836.83
468	18	45	8	13	37	3910.5	-6075	-6051	-2738.5	458	-2837.17
469	63	63	0	63	63	-2579	-12614	-12602.5	-9265.17	665	-2855.83
470	44	63	4	39	59	-365.5	-374	-332	-357.167	245	-2893.83
471	0	0	63	0	0	6933.5	6917.5	6968	6939.667	8	-2899
472	4	5	37	5	1	-2751.5	-2644.5	-2619	-2671.67	454	-2905.5
473	0	10	5	10	0	8652.5	-1287	-1273	2030.833	130	-2947.5
474	0	10	5	10	0	-1338.5	-1286	-1259	-1294.5	321	-2956.17
475	18	17	15	7	3	7035	-3023.5	7073	3694.833	73	-2961.17
476	18	17	15	7	3	6876	-3046.5	-3020.5	269.6667	206	-2965.83
477	60	61	63	0	12	-9851	-10075	-10022	-9982.67	673	-2978
478	9	28	11	14	3	6682.5	-3296.5	-3287	33	219	-2990.17
479	5	0	9	6	1	8824	-1092.5	-1073	2219.5	120	-3017.67
480	5	0	9	6	1	-1130	8919.5	8939.5	5576.333	34	-3030.67
481	24	26	24	23	22	4032	-5992.5	4056	698.5	193	-3037
482	40	41	39	36	43	15.5	-9973	-9952.5	-6636.67	625	-3045
483	60	60	58	56	63	-4794.5	-4832.5	-4784	-4803.67	575	-3076.67
484	60	60	58	56	63	-4765	-4777	-4734	-4758.67	570	-3099.17
485	1	0	0	24	0	8740	-1267.5	-1249	2074.5	128	-3119.83
486	5	58	63	47	45	-10932.5	-11173	-11120	-11075.2	682	-3124.5
487	2	8	24	26	17	6219.5	6184.5	6223.5	6209.167	16	-3133.33
488	2	0	0	28	0	8490	-1516.5	-1495	1826.167	142	-3174.83
489	4	23	63	5	55	-7539	2468	-7723.5	-4264.83	551	-3180.33
490	8	21	6	22	23	6039	-3994	6057.5	2700.833	101	-3201.67
491	8	21	6	22	23	6006	-4013.5	-3994.5	-667.333	272	-3204.83
492	0	0	6	32	0	-1947	8072.5	8089	4738.167	47	-3208.83
493	30	63	7	9	63	1445.5	1433	1490.5	1456.333	158	-3213.17
494	0	1	0	31	0	8377	-1624	-1604.5	1716.167	147	-3214
495	63	15	42	14	57	-9583.5	-9821	-9773	-9725.83	669	-3217.17

496	17	29	29	17	4	5242	5230	5277	5249.667	36	-3257.67
497	0	0	0	37	0	8071.5	-1894.5	-1872.5	1434.833	159	-3260.67
498	63	63	63	0	14	-10182.5	-179.5	-10370	-6910.67	630	-3281.33
499	20	9	9	30	2	6438	-3541.5	-3522.5	-208.667	238	-3286
500	20	9	9	30	2	6439	-3535.5	-3514	-203.5	237	-3299.83
501	63	57	17	53	7	-9887.5	-10125	-10072.5	-10028.3	674	-3302
502	63	57	17	53	7	131	-9886.5	150.5	-3201.67	490	-3302
503	20	28	19	28	18	4299.5	-5673.5	-5655.5	-2343.17	425	-3314.17
504	63	63	63	50	63	-15132.5	-15373.5	-15320.5	-15275.5	688	-3315.17
505	63	63	63	50	63	-5014.5	-5026	-4984.5	-5008.33	582	-3334.33
506	3	31	38	32	40	2854	-7185	-7175.5	-3835.5	532	-3351.83
507	3	31	38	32	40	2827	-7203.5	2849.5	-509	254	-3355.67
508	4	48	60	46	31	588.5	-9472.5	619.5	-2754.83	461	-3377.17
509	1	8	17	8	50	5838.5	-4217	5878	2499.833	107	-3395.67
510	0	0	0	10	60	6573	-3491	-3461.5	-126.5	228	-3407.17
511	0	0	0	10	60	6565.5	-3471.5	-3450	-118.667	227	-3409.83
512	5	27	62	5	34	3362.5	-6664.5	-6643.5	-3315.17	504	-3442.33
513	9	14	2	11	55	5536	-4534.5	-4522	-1173.5	308	-3512.67
514	0	0	0	7	55	6967.5	-3074.5	-3052.5	280.1667	205	-3527.17
515	25	5	7	12	53	4940.5	4923	4979.5	4947.667	41	-3545.83
516	0	0	0	6	57	6913.5	-3134.5	6914	3564.333	75	-3570.67
517	0	0	0	6	57	6919	-3124.5	-3102	230.8333	210	-3576.33
518	63	17	39	21	42	924	-9123.5	968	-2410.5	432	-3590.67
519	0	0	0	13	59	6424.5	-3600	6458.5	3094.333	88	-3608.67
520	0	0	0	13	59	6468	-3573	-3546.5	-217.167	240	-3627
521	63	63	63	0	7	119	-9851	-9836.5	-6522.83	622	-3627.83
522	16	11	3	17	44	5514.5	-4548.5	-4526	-1186.67	310	-3630.67
523	18	28	4	14	59	3821	-6193	3849	492.3333	199	-3651.33
524	18	28	4	14	59	3900.5	-6140.5	3914.5	558.1667	198	-3674.67
525	63	63	57	54	63	-4934.5	-14977	-14955.5	-11622.3	684	-3713
526	4	37	53	31	34	2135.5	2123.5	2165	2141.333	123	-3726
527	4	28	49	19	37	3167	-6864	3189.5	-169.167	231	-3728.5
528	4	28	49	19	37	3172	-6862.5	-6847.5	-3512.67	513	-3761.33
529	4	0	0	0	63	6748	-3316.5	-3301	43.5	218	-3790.5
530	4	63	63	63	0	415.5	-9638.5	-9626.5	-6283.17	616	-3806.17
531	4	55	60	54	16	525.5	-9496.5	-9491	-6154	612	-3813.33
532	0	46	60	44	28	1148.5	1125	1173.5	1149	171	-3835.5
533	12	41	50	36	36	1275.5	-8771	1282.5	-2071	397	-3841.67
534	0	51	63	52	28	337.5	-9721	330.5	-3017.67	479	-3860
535	26	47	58	24	32	689.5	-9372	726	-2652.17	452	-3865.5
536	0	45	56	63	32	206	-9830.5	224.5	-3133.33	487	-3876.67
537	0	45	56	63	32	259.5	222	276	252.5	208	-3907.5
538	1	43	63	44	35	729.5	-9325	732.5	-2621	449	-3934.17
539	22	50	56	46	42	-754	-10819.5	-763	-4112.17	549	-3945.33
540	60	60	27	56	63	-3220	-3234	-3188	-3214	494	-3963.83
541	60	60	27	56	63	-3215	-3227	-3184.5	-3208.83	492	-3989.67
542	14	20	32	7	40	4312	-5675	-5660	-2341	424	-4008.67
543	0	18	58	5	38	4067.5	-5954.5	-5944	-2610.33	447	-4018.67
544	0	18	58	5	38	4062	-5951.5	-5936.5	-2608.67	446	-4059.33
545	13	18	43	11	41	3712	-6298	-6297.5	-2961.17	475	-4062

546	0	20	47	1	37	4760	-5263.5	-5239.5	-1914.33	387	-4091.17
547	34	42	56	3	20	2250.5	-7779	-7761.5	-4430	561	-4098.5
548	56	59	62	1	6	763.5	-9238.5	-9225	-5900	604	-4110.5
549	56	59	62	1	6	674	-9251	-9242	-5939.67	607	-4112.17
550	2	17	44	6	40	4584	-5457.5	-5430.5	-2101.33	402	-4219
551	11	25	37	27	26	3728	-6309	-6287.5	-2956.17	474	-4264.83
552	11	25	37	27	26	3678	-6310	-6302	-2978	477	-4310.17
553	0	13	53	0	52	4143	-5894.5	-5882.5	-2544.67	439	-4316.5
554	0	1	41	0	35	6179.5	-3859	6187	2835.833	98	-4328.83
555	26	43	7	15	51	2904	-7098.5	-7089.5	-3761.33	528	-4330.17
556	22	63	7	13	59	1837.5	-8209	1836	-1511.83	347	-4340.17
557	32	59	25	10	40	1743	1734	1786.5	1754.5	145	-4344
558	41	57	43	5	26	1424	-8619	1420.5	-1924.83	389	-4378
559	63	0	63	0	0	3689	-6335.5	-6324	-2990.17	478	-4406.5
560	56	27	62	1	6	2268.5	-7656.5	-7644	-4344	557	-4409.67
561	21	63	0	16	61	1819	-8101.5	-8093	-4791.83	574	-4430
562	22	63	4	15	58	1944.5	1934.5	1983.5	1954.167	135	-4491.17
563	27	60	8	28	36	2092.5	2077.5	2142	2104	125	-4525
564	21	63	6	0	63	2368.5	-7669.5	2378	-974.333	298	-4613.17
565	29	60	24	29	56	143.5	-9910	152	-3204.83	491	-4629.5
566	19	63	0	0	54	3274	3227	3273.5	3258.167	79	-4676.5
567	53	27	43	14	30	1686	-8353.5	1700.5	-1655.67	356	-4679.67
568	61	0	21	22	58	1911	-8126	1922.5	-1430.83	333	-4715.67
569	52	20	30	23	38	1921	1881.5	1940	1914.167	138	-4716.83
570	62	4	34	13	50	1868	-8175	1880	-1475.67	346	-4758.67
571	57	18	37	23	53	636.5	-9413.5	634.5	-2714.17	456	-4759.17
572	57	6	27	13	35	3162	3126	3178.5	3155.5	85	-4773
573	48	54	45	8	10	1768.5	-8270	1783	-1572.83	351	-4776
574	50	54	63	0	12	985.5	-8995	-8981.5	-5663.67	599	-4791.83
575	52	55	58	17	28	-567.5	-10546.5	-10532.5	-7215.5	638	-4803.67
576	54	56	56	33	46	-2241	-12282.5	-2233.5	-5585.67	595	-4815.33
577	49	54	61	0	10	1358.5	1320	1365	1347.833	163	-4833.33
578	49	54	61	1	10	1177	-8801.5	-8782.5	-5469	593	-4865.67
579	50	54	18	50	27	-23	-10001.5	-9987.5	-6670.67	628	-4887.83
580	42	50	10	50	0	2433	2412	2462.5	2435.833	113	-4925.67
581	42	50	10	50	0	2355.5	-7652	2408	-962.833	293	-4976.83
582	11	0	0	5	0	-864.5	9170.5	9193	5833	24	-5008.33
583	6	9	7	8	0	-1583	8468.5	8489	5124.833	37	-5116
584	8	3	1	6	0	-1004.5	-935.5	-913	-951	292	-5118
585	7	0	21	3	0	-1629	8419	8439.5	5076.5	39	-5125.33
586	3	0	42	2	0	-2466	-2392.5	-2364	-2407.5	431	-5157.67
587	63	0	0	63	0	-6451	-6345.5	-6325.5	-6374	619	-5185
588	37	0	0	34	0	6425.5	-3583	6473.5	3105.333	87	-5260.17
589	14	1	0	5	5	8693	-1287.5	-1265	2046.833	129	-5264.83
590	6	0	0	5	0	-635.5	9424.5	-555.5	2744.5	100	-5310.83
591	30	5	11	9	20	-3805	-4028	-3969.5	-3934.17	538	-5374.67
592	7	3	8	12	6	8160	-1828.5	-1801.5	1510	154	-5455.33
593	5	5	16	19	11	-2882	-2825.5	-2803	-2836.83	467	-5469
594	1	36	44	45	40	-8405	-8324	-8297.5	-8342.17	656	-5527.17
595	15	21	3	9	21	6609	-3460	6636.5	3261.833	78	-5585.67

596	19	42	6	13	42	3872.5	-6124.5	-6100	-2784	463	-5624.17
597	19	16	3	23	3	6827	-3202.5	6851	3491.833	76	-5637.83
598	1	0	0	0	0	9844	-90	-63.5	3230.167	80	-5660.83
599	57	63	18	63	10	-10819.5	-10828	-10800.5	-10816	680	-5663.67
600	11	11	3	9	2	8195	-1837	8260	4872.667	43	-5854.5
601	9	0	0	1	0	-623	-535.5	-512	-556.833	257	-5857.17
602	18	40	32	21	6	-5912.5	-6130	4141	-2633.83	450	-5879.5
603	7	8	8	9	0	8341	-1644.5	-1627	1689.833	149	-5884.17
604	7	8	6	7	0	-1507.5	-1437.5	-1409	-1451.33	338	-5900
605	7	10	11	11	2	-2156.5	-2084	-2066.5	-2102.33	403	-5904
606	7	9	9	9	0	-1826.5	-1736	-1713.5	-1758.67	368	-5935.5
607	7	7	7	12	0	-1766	-1684.5	-1666	-1705.5	363	-5939.67
608	7	9	7	4	0	-1452	-1386	-1358	-1398.67	329	-5952.83
609	2	3	6	31	1	-2261	-2191	-2163.5	-2205.17	417	-6026.67
610	7	6	7	17	0	-1919.5	8123	8138	4780.5	45	-6112.67
611	5	5	26	5	0	-2149	-2081.5	-2059	-2096.5	401	-6153
612	2	3	44	3	0	-2737	-2643	-2619.5	-2666.5	453	-6154
613	35	36	4	36	0	-5704.5	-5594	-5574	-5624.17	596	-6163.33
614	4	7	6	8	19	7749	-2240.5	-2225.5	1094.333	175	-6194.33
615	10	9	8	8	0	-1813	-1760.5	-1740	-1771.17	371	-6238
616	10	6	8	8	5	-1975.5	-1886.5	-1862.5	-1908.17	385	-6283.17
617	4	10	6	8	0	-1509	-1432	-1408.5	-1449.83	337	-6316.83
618	29	2	12	9	20	-3701.5	-3637.5	-3615	-3651.33	523	-6326.33
619	5	8	13	14	6	7662	-2326	-2297	1013	180	-6374
620	4	8	18	20	11	-3159	-3082.5	-3056	-3099.17	484	-6399
621	0	8	63	63	63	90	-9874.5	-9853.5	-6546	623	-6417.5
622	1	8	44	45	40	3185	3193	3201	3193	83	-6522.83
623	9	24	7	10	1	7497.5	-2540.5	7515.5	4157.5	62	-6546
624	5	0	7	6	0	-1054.5	-943.5	-922	-973.333	297	-6575.67
625	26	63	9	19	63	-9064.5	971	992.5	-2367	428	-6636.67
626	18	34	9	16	0	6196	6180	6232	6202.667	17	-6666.5
627	0	0	5	0	0	9654	-298.5	-275.5	3026.667	89	-6669
628	59	63	17	62	7	-10686	-10677	-10620	-10661	678	-6670.67
629	8	16	14	10	0	7589.5	-2437.5	7654.5	4268.833	57	-6681.83
630	6	0	0	6	0	-747.5	-641.5	-621.5	-670.167	273	-6910.67
631	18	37	36	19	4	-5754.5	-5978	-5920	-5884.17	603	-6936.67
632	6	9	28	6	2	7386.5	-2594.5	-2577	738.3333	190	-7029
633	8	11	0	14	2	-1896.5	-1785	-1770	-1817.17	374	-7057.5
634	13	8	10	10	6	-2454	-2383	-2359	-2398.67	430	-7111.67
635	20	6	11	9	11	-2974.5	-2882.5	-2859.5	-2905.5	472	-7190
636	63	0	63	0	63	467.5	-9474	-9452.5	-6153	611	-7205.83
637	45	2	37	5	39	3643.5	3630.5	3686.5	3653.5	74	-7214.83
638	0	63	0	63	0	3720.5	-6319	-6299	-2965.83	476	-7215.5
639	4	37	5	37	1	5763.5	-4232.5	-4222.5	-897.167	290	-7216.5
640	5	9	15	15	7	7398	-2588	-2568	747.3333	189	-7220.33
641	4	9	19	21	12	-3369	-3275	-3255.5	-3299.83	500	-7272
642	1	4	44	45	40	3237.5	-6723.5	-6701	-3395.67	509	-7361.17
643	8	10	8	8	0	8350.5	-1687.5	8367	5010	40	-7366.5
644	7	10	9	9	1	-1921.5	-1835	-1817	-1857.83	380	-7422.17
645	12	18	10	13	14	-3470	-3390	-3361.5	-3407.17	510	-7614.67

646	2	2	10	7	0	8902.5	-1079	-1054.5	2256.333	119	-7626.83
647	29	63	9	20	63	-9266.5	770.5	791	-2568.33	444	-7677.33
648	21	28	12	25	4	5578.5	5529	5575.5	5561	35	-7756.67
649	34	45	13	39	5	3074.5	-6839	-6817	-3527.17	514	-7969
650	56	63	39	59	35	-2642.5	-12649	-12634.5	-9308.67	666	-8022.33
651	10	16	16	12	3	7211	7163.5	7255	7209.833	6	-8055.17
652	14	23	23	15	3	5995.5	-3939	-3912.5	-618.667	264	-8168.33
653	35	63	63	30	8	-43.5	-9989.5	-9974	-6669	627	-8258.83
654	26	46	46	23	6	2608	-7396.5	-7389.5	-4059.33	544	-8264.17
655	1	3	19	20	1	7740	-2253	-2236.5	1083.5	177	-8275
656	3	5	0	34	1	-2246	-2186	-2162.5	-2198.17	415	-8342.17
657	14	4	8	18	6	-2568	7472.5	7487	4130.5	64	-8419.33
658	0	4	4	36	0	-2319	-2225.5	-2206.5	-2250.33	419	-8465.33
659	38	4	13	0	20	-3809	6223	6239	2884.333	94	-8516.67
660	2	5	12	27	6	7340	-2628.5	-2613.5	699.3333	192	-8582.33
661	2	7	18	26	12	-3328.5	-3276.5	-3253	-3286	499	-8773
662	2	63	63	0	63	394.5	-9562.5	-9546	-6238	615	-8855
663	2	36	44	13	40	3293.5	-6749	3296.5	-53	225	-8928.5
664	2	0	0	63	0	6775.5	-3260.5	-3241.5	91.16667	215	-9119.5
665	2	2	3	45	1	-2699.5	7322.5	7343.5	3988.833	68	-9265.17
666	5	10	6	26	28	-3804.5	6221	6241	2885.833	93	-9308.67
667	0	0	6	28	0	8342.5	-1707.5	-1680.5	1651.5	150	-9535.5
668	27	63	9	16	63	-8949.5	1069.5	1091.5	-2262.83	420	-9541
669	20	26	8	29	4	5696	5680.5	5727.5	5701.333	28	-9725.83
670	0	0	4	25	0	8498	-1487	-1469	1847.333	140	-9839.33
671	63	63	17	56	10	-10494	-477	-10673.5	-7214.83	637	-9854.5
672	3	9	13	24	2	7441	-2585.5	7500.5	4118.667	67	-9873.67
673	1	0	0	30	0	-1658	-1586.5	-1558.5	-1601	353	-9982.67
674	18	34	36	14	5	-5383	-5625.5	-5573	-5527.17	594	-10028.3
675	0	0	44	3	6	7279.5	-2692.5	-2675.5	637.1667	195	-10384.7
676	9	1	46	3	5	-3334	-3234	-3214	-3260.67	497	-10593.3
677	17	3	28	6	10	6688.5	-3239.5	-3219	76.66667	216	-10639.2
678	45	34	6	36	39	1901.5	-8039	-8013	-4716.83	569	-10661
679	0	0	52	5	1	7145.5	7120.5	7181.5	7149.167	7	-10760.8
680	8	21	45	6	21	-5205.5	-5104	-5066.5	-5125.33	585	-10816
681	16	42	27	11	42	3061	-6922.5	-6910.5	-3590.67	518	-10872.7
682	16	21	47	18	2	4827.5	-5208.5	4841.5	1486.833	156	-11075.2
683	32	42	31	36	5	2618.5	-7346	-7328.5	-4018.67	543	-11082.5
684	56	63	8	59	35	-1093.5	-11090	-11086.5	-7756.67	648	-11622.3
685	4	5	51	3	0	6911	6868	6954	6911	9	-12596
686	9	1	4	9	42	-3424.5	-3301.5	-3277	-3334.33	505	-12925.3
687	17	3	7	9	28	6851.5	-3191	-3170	163.5	211	-14213.8
688	63	63	63	9	0	67.5	-9907.5	-9887	-6575.67	624	-15275.5
689	45	34	37	9	8	3263.5	-6699.5	-6695.5	-3377.17	508	-16014.8

Appendix 5: Regression Analysis

The whole model includes parameters polynomial to fifth degree and full factorial. The variability in the data is explained 57% despite the huge number of the parameters. Each complete run among the others was performed separately and under the same conditions, which provides the error terms to be independently identically distributed, and Shapiro-Wilkinson test verified that they are also normal. Residual plot shows no significant pattern but an even distribution and constant variance. The details are shown below:

Response: weighted objective

Summary of Fit

RSquare	0.572761
RSquare Adj	0.462156
Root Mean Square Error	2796.682
Mean of Response	-1400.57
Observations (or Sum Wgts)	249

Lack of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack of Fit	147	1284339016	8737000	1.7032
Pure Error	50	256483011	5129660	Prob>F
Total Error	197	1540822027		0.0157
Max RSq				
0.9289				

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	5952.1424	1520.016	3.92	0.0001
Aircraft1	-750.7417	361.5091	-2.08	0.0391
Aircraft2	90.399428	330.1415	0.27	0.7845
Aircraft1*Aircraft2	2.9002642	3.249142	0.89	0.3731
Aircraft3	-348.1698	356.4375	-0.98	0.3299
Aircraft1*Aircraft3	7.3422125	5.308086	1.38	0.1682
Aircraft2*Aircraft3	11.365968	10.67632	1.06	0.2884
Aircraft1*Aircraft2*Aircraft3	-0.223981	0.168747	-1.33	0.1859
Aircraft4	-684.4209	291.7342	-2.35	0.0200
Aircraft1*Aircraft4	1.4355941	3.089653	0.46	0.6427
Aircraft2*Aircraft4	1.9149344	7.350865	0.26	0.7947
Aircraft1*Aircraft2*Aircraft4	-0.041533	0.113525	-0.37	0.7149
Aircraft3*Aircraft4	4.4079979	5.189752	0.85	0.3967
Aircraft1*Aircraft3*Aircraft4	-0.10655	0.092628	-1.15	0.2514
Aircraft2*Aircraft3*Aircraft4	-0.187256	0.189892	-0.99	0.3253
Aircraft1*Aircraft2*Aircraft3*Aircraft4	0.0034392	0.002924	1.18	0.2409
Aircraft5	-106.3785	299.3437	-0.36	0.7227
Aircraft1*Aircraft5	6.3811637	3.051069	2.09	0.0378
Aircraft2*Aircraft5	2.5785061	2.604744	0.99	0.3234
Aircraft1*Aircraft2*Aircraft5	-0.124258	0.066351	-1.87	0.0626
Aircraft3*Aircraft5	1.6071497	6.294813	0.26	0.7987
Aircraft1*Aircraft3*Aircraft5	-0.17233	0.095284	-1.81	0.0720
Aircraft2*Aircraft3*Aircraft5	-0.095878	0.239275	-0.40	0.6891
Aircraft1*Aircraft2*Aircraft3*Aircraft5	0.0038655	0.003666	1.05	0.2929
Aircraft4*Aircraft5	1.8638123	1.562528	1.19	0.2344
Aircraft1*Aircraft4*Aircraft5	-0.041985	0.09958	-0.42	0.6738
Aircraft2*Aircraft4*Aircraft5	-0.057478	0.123623	-0.46	0.6425

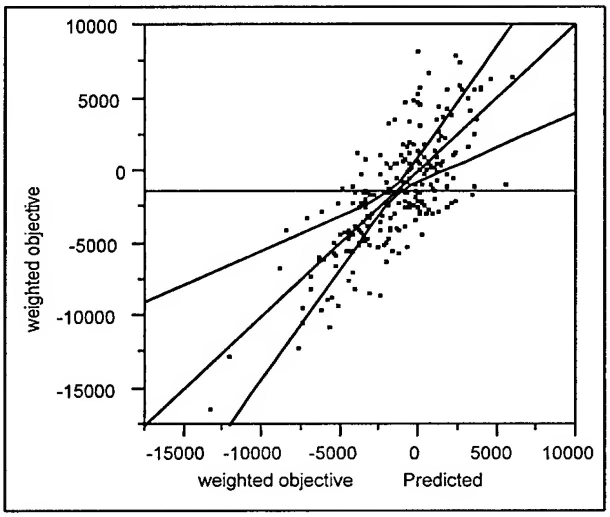
Aircraft1*Aircraft2*Aircraft4*Aircraft5	0.0007991	0.002316	0.34	0.7305
Aircraft3*Aircraft4*Aircraft5	-0.035482	0.103133	-0.34	0.7312
Aircraft1*Aircraft3*Aircraft4*Aircraft5	0.001326	0.002295	0.58	0.5641
Aircraft2*Aircraft3*Aircraft4*Aircraft5	0.0019465	0.004276	0.46	0.6495
Aircraft1*Aircraft2*Aircraft3*Aircraft4*Aircraft5	-0.000043	0.00007	-0.62	0.5359
Aircraft1*Aircraft1	48.61383	36.03725	1.35	0.1789
Aircraft1*Aircraft1*Aircraft1	-1.664394	1.519078	-1.10	0.2746
Aircraft1*Aircraft1*Aircraft1*Aircraft1	0.0261299	0.027322	0.96	0.3401
Aircraft1*Aircraft1*Aircraft1*Aircraft1*Aircraft1	-0.000153	0.000175	-0.87	0.3828
Aircraft2*Aircraft2	-7.313304	33.80103	-0.22	0.8289
Aircraft2*Aircraft2*Aircraft2	-0.109586	1.439094	-0.08	0.9394
Aircraft2*Aircraft2*Aircraft2*Aircraft2	0.005922	0.026153	0.23	0.8211
Aircraft2*Aircraft2*Aircraft2*Aircraft2*Aircraft2	-0.000051	0.00017	-0.30	0.7622
Aircraft3*Aircraft3	13.002956	38.23385	0.34	0.7342
Aircraft3*Aircraft3*Aircraft3	-0.968784	1.515205	-0.64	0.5233
Aircraft3*Aircraft3*Aircraft3*Aircraft3	0.0224916	0.026537	0.85	0.3977
Aircraft3*Aircraft3*Aircraft3*Aircraft3*Aircraft3	-0.000164	0.000167	-0.98	0.3294
Aircraft4*Aircraft4	70.240404	31.28921	2.24	0.0259
Aircraft4*Aircraft4*Aircraft4	-2.864449	1.375211	-2.08	0.0385
Aircraft4*Aircraft4*Aircraft4*Aircraft4	0.048631	0.025701	1.89	0.0599
Aircraft4*Aircraft4*Aircraft4*Aircraft4*Aircraft4	-0.000291	0.00017	-1.71	0.0894
Aircraft5*Aircraft5	17.33458	33.67648	0.51	0.6073
Aircraft5*Aircraft5*Aircraft5	-1.170897	1.43315	-0.82	0.4149
Aircraft5*Aircraft5*Aircraft5*Aircraft5	0.0262925	0.025463	1.03	0.3031
Aircraft5*Aircraft5*Aircraft5*Aircraft5*Aircraft5	-0.000191	0.00016	-1.20	0.2331

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Aircraft1	1	1	33730973	4.3126	0.0391
Aircraft2	1	1	586432	0.0750	0.7845
Aircraft1*Aircraft2	1	1	6231949	0.7968	0.3731
Aircraft3	1	1	7462795	0.9541	0.3299
Aircraft1*Aircraft3	1	1	14964568	1.9133	0.1682
Aircraft2*Aircraft3	1	1	8864541	1.1334	0.2884
Aircraft1*Aircraft2*Aircraft3	1	1	13779692	1.7618	0.1859
Aircraft4	1	1	43048494	5.5039	0.0200
Aircraft1*Aircraft4	1	1	1688613	0.2159	0.6427
Aircraft2*Aircraft4	1	1	530783	0.0679	0.7947
Aircraft1*Aircraft2*Aircraft4	1	1	1046876	0.1338	0.7149
Aircraft3*Aircraft4	1	1	5642555	0.7214	0.3967
Aircraft1*Aircraft3*Aircraft4	1	1	10349239	1.3232	0.2514
Aircraft2*Aircraft3*Aircraft4	1	1	7605765	0.9724	0.3253
Aircraft1*Aircraft2*Aircraft3*Aircraft4	1	1	10821652	1.3836	0.2409
Aircraft5	1	1	987765	0.1263	0.7227
Aircraft1*Aircraft5	1	1	34212266	4.3742	0.0378
Aircraft2*Aircraft5	1	1	7664653	0.9800	0.3234
Aircraft1*Aircraft2*Aircraft5	1	1	27431227	3.5072	0.0626
Aircraft3*Aircraft5	1	1	509839	0.0652	0.7987
Aircraft1*Aircraft3*Aircraft5	1	1	25584250	3.2710	0.0720
Aircraft2*Aircraft3*Aircraft5	1	1	1255831	0.1606	0.6891
Aircraft1*Aircraft2*Aircraft3*Aircraft5	1	1	8697478	1.1120	0.2929
Aircraft4*Aircraft5	1	1	11128464	1.4228	0.2344
Aircraft1*Aircraft4*Aircraft5	1	1	1390326	0.1778	0.6738
Aircraft2*Aircraft4*Aircraft5	1	1	1690809	0.2162	0.6425
Aircraft1*Aircraft2*Aircraft4*Aircraft5	1	1	930883	0.1190	0.7305
Aircraft3*Aircraft4*Aircraft5	1	1	925766	0.1184	0.7312
Aircraft1*Aircraft3*Aircraft4*Aircraft5	1	1	2611136	0.3338	0.5641
Aircraft2*Aircraft3*Aircraft4*Aircraft5	1	1	1620813	0.2072	0.6495
Aircraft1*Aircraft2*Aircraft3*Aircraft4*Aircraft5	1	1	3007214	0.3845	0.5359
Aircraft1*Aircraft1	1	1	14233202	1.8198	0.1789
Aircraft1*Aircraft1*Aircraft1	1	1	9389411	1.2005	0.2746
Aircraft1*Aircraft1*Aircraft1*Aircraft1	1	1	7153815	0.9146	0.3401

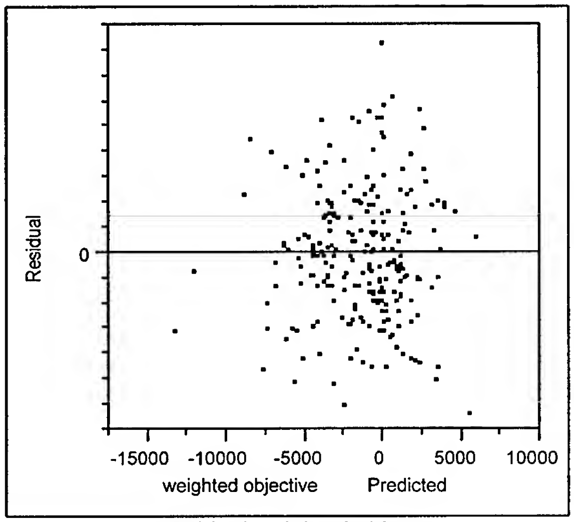
Aircraft1*Aircraft1*Aircraft1*Aircraft1*Aircraft1	1	1	5984250	0.7651	0.3828
Aircraft2*Aircraft2	1	1	366145	0.0468	0.8289
Aircraft2*Aircraft2*Aircraft2	1	1	45354	0.0058	0.9394
Aircraft2*Aircraft2*Aircraft2*Aircraft2	1	1	401031	0.0513	0.8211
Aircraft2*Aircraft2*Aircraft2*Aircraft2*Aircraft2	1	1	718329	0.0918	0.7622
Aircraft3*Aircraft3	1	1	904637	0.1157	0.7342
Aircraft3*Aircraft3*Aircraft3	1	1	3197399	0.4088	0.5233
Aircraft3*Aircraft3*Aircraft3*Aircraft3	1	1	5618498	0.7183	0.3977
Aircraft3*Aircraft3*Aircraft3*Aircraft3*Aircraft3	1	1	7476544	0.9559	0.3294
Aircraft4*Aircraft4	1	1	39415871	5.0395	0.0259
Aircraft4*Aircraft4*Aircraft4	1	1	33933558	4.3385	0.0385
Aircraft4*Aircraft4*Aircraft4*Aircraft4	1	1	28002853	3.5803	0.0599
Aircraft4*Aircraft4*Aircraft4*Aircraft4*Aircraft4	1	1	22793760	2.9143	0.0894
Aircraft5*Aircraft5	1	1	2072333	0.2650	0.6073
Aircraft5*Aircraft5*Aircraft5	1	1	5220840	0.6675	0.4149
Aircraft5*Aircraft5*Aircraft5*Aircraft5	1	1	8339435	1.0662	0.3031
Aircraft5*Aircraft5*Aircraft5*Aircraft5*Aircraft5	1	1	11188150	1.4304	0.2331

Whole-Model Test

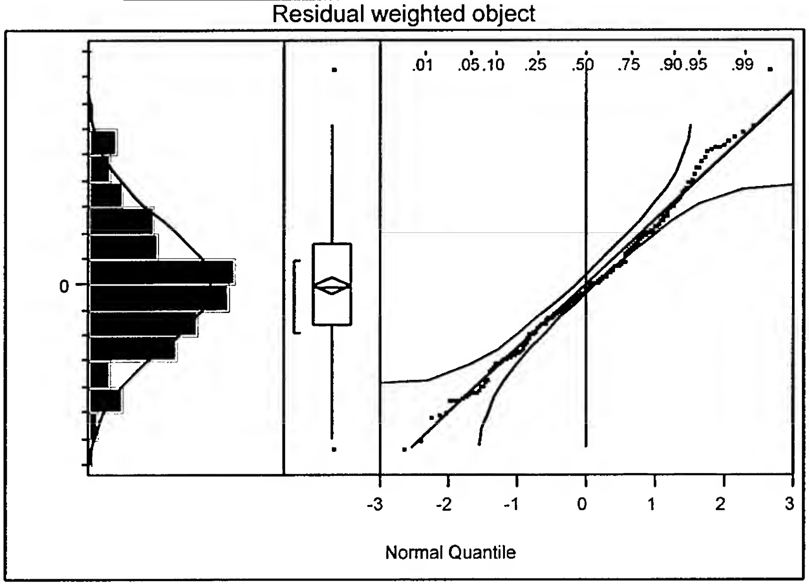


Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	51	2065643002	40502804	5.1784
Error	197	1540822027	7821432	Prob>F
C Total	248	3606465029		<.0001



Residual weighted object



	Quantiles	
maximum	100.0%	8390.9
	99.5%	7856.2
	97.5%	5455.7
	90.0%	3339.7
quartile	75.0%	1610.6
median	50.0%	-63.0
quartile	25.0%	-1534.6
	10.0%	-2973.6
	2.5%	-4474.0
	0.5%	-6208.4
minimum	0.0%	-6281.9

Moments	
Mean	-0.000
Std Dev	2492.587
Std Error Mean	157.961
Upper 95% Mean	311.121
Lower 95% Mean	-311.121
N	249.000
Sum Weights	249.000

Test for Normality
Shapiro-Wilk W Test

W	Prob<W
0.982146	0.4106

To reduce the number of parameters, we run stepwise regression. We tested the assumptions of the resulting model. The error terms were independently identically distributed, and their normality is verified by Shapiro-Wilkinson test. The model residuals show no significant pattern and the constancy of variance is verified by Breush-Pegan test.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	1.96969e15	2.462e14	2.6492
Error	240	2.2305e+16	9.294e13	Prob>F
C Total	248	2.42747e16		0.0084

The above ANOVA table obtained by regressing the squared residuals over the reduced model is used in testing the variance. The chi-square statistic obtained is 16,4. This is less than 20.09 at .01 significance level showing constant variance. In addition, given that the whole model could explain the variability in the data 57%, the reduced model performs well by 46%. Here is the model:

y = 2136.4525 + 10.198999 Aircraft1- 33.97995 Aircraft2- 91.29319 Aircraft3+ 7.0619104 Aircraft4-1.38817 Aircraft1*Aircraft4-15.1685 Aircraft5- 0.816226Aircraft3*Aircraft5+ 0.9511885Aircraft3*Aircraft3 + error

By examining the stationary points of this function, we find that maximum values are located around x_1=5 and x_4=7. The approximation function has other stationary points in areas where x_3 and x_5 take negative values.

The details of the regression are given below:

Response: weighted objective

Summary of Fit

RSquare	0.464923
RSquare Adj	0.447087
Root Mean Square Error	2835.591
Mean of Response	-1400.57
Observations (or Sum Wgts)	249

Lack of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack of Fit	190	1673254879	8806605	1.7168
Pure Error	50	256483011	5129660	Prob>F
Total Error	240	1929737890		0.0130
				Max RSq
				0.9289

Parameter Estimates

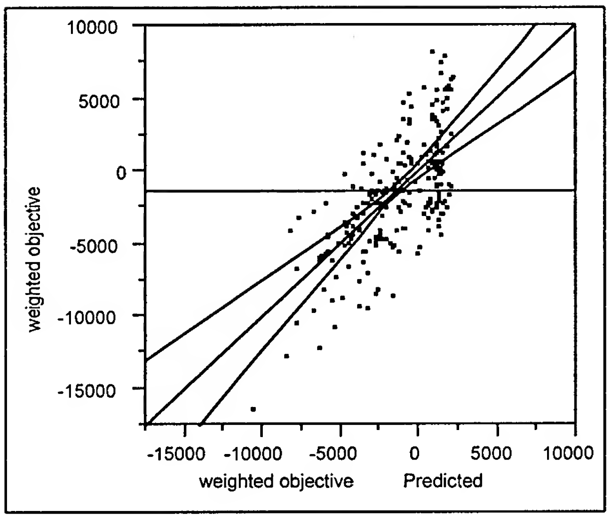
Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	2136.4525	542.6446	3.94	0.0001
Aircraft1	10.198999	16.99174	0.60	0.5489
Aircraft2	-33.97995	9.142528	-3.72	0.0003
Aircraft3	-91.29319	39.37482	-2.32	0.0213
Aircraft4	7.0619104	17.89208	0.39	0.6934
Aircraft1*Aircraft4	-1.38817	0.423166	-3.28	0.0012
Aircraft5	-15.1685	11.42189	-1.33	0.1854

Aircraft3*Aircraft5	-0.816226	0.398438	-2.05	0.0416
Aircraft3*Aircraft3	0.9511885	0.562623	1.69	0.0922

Effect Test

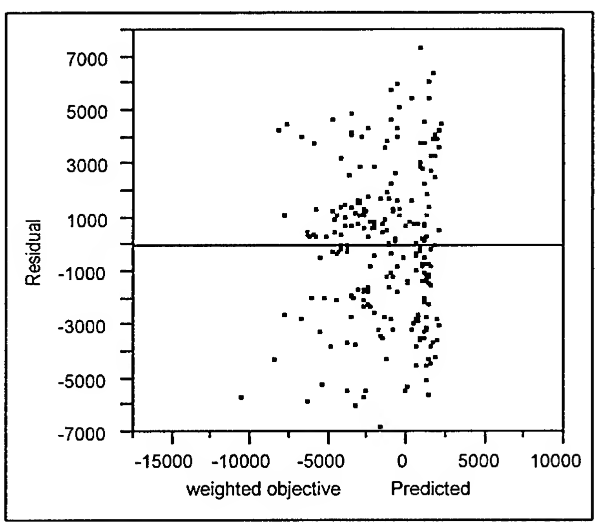
Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Aircraft1	1	1	2896852	0.3603	0.5489
Aircraft2	1	1	111070825	13.8138	0.0003
Aircraft3	1	1	43224180	5.3758	0.0213
Aircraft4	1	1	1252593	0.1558	0.6934
Aircraft1*Aircraft4	1	1	86526933	10.7613	0.0012
Aircraft5	1	1	14180661	1.7636	0.1854
Aircraft3*Aircraft5	1	1	33743262	4.1966	0.0416
Aircraft3*Aircraft3	1	1	22981843	2.8582	0.0922

Whole-Model Test

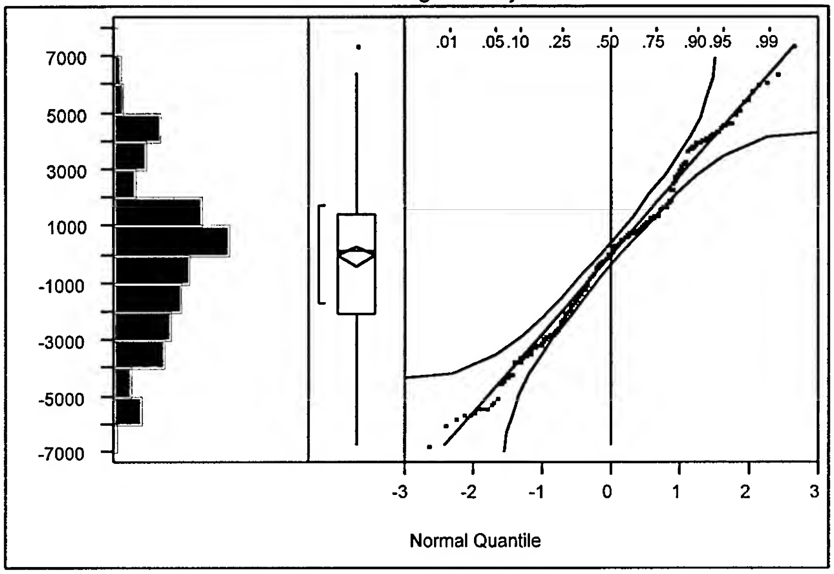


Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	8	1676727139	2.0959e8	26.0667
Error	240	1929737890	8040575	Prob>F
C Total	248	3606465029		<.0001



Residual weighted object



Quantiles

maximum	100.0%	7439.1
	99.5%	7192.4
	97.5%	5535.8
	90.0%	4013.4
quartile	75.0%	1472.8
median	50.0%	156.1
quartile	25.0%	-2022.1
	10.0%	-3549.6
	2.5%	-5479.4
	0.5%	-6561.0
minimum	0.0%	-6760.2

Moments

Mean	-0.000
Std Dev	2789.480
Std Error Mean	176.776
Upper 95% Mean	348.178
Lower 95% Mean	-348.178
N	249.000
Sum Weights	249.000

Test for Normality
Shapiro-Wilk W Test

W	Prob<W
0.975069	0.0559

Parameter estimates below describe the model obtained by regressing the local optima of multi-scenario objective function values over explanatory variables, *i.e.*, aircraft types. Examining the stationary points, we have found that this regression function has a maximum where x_3 is close to 18.

Response: weighted objective

Summary of Fit

RSquare	0.95112
RSquare Adj	0.918534
Root Mean Square Error	1045.427
Mean of Response	2966.439
Observations (or Sum Wgts)	11

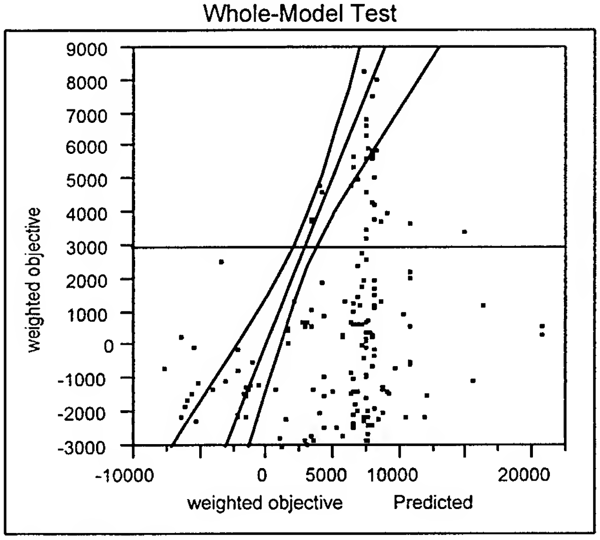
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	7389.4478	808.5816	9.14	<.0001
Aircraft1	-272.3735	33.55304	-8.12	0.0002
Aircraft2	53.682613	42.00488	1.28	0.2485
Aircraft3	211.52482	43.80634	4.83	0.0029
Aircraft2*Aircraft3	-3.19308	0.92555	-3.45	0.0136

Effect Test

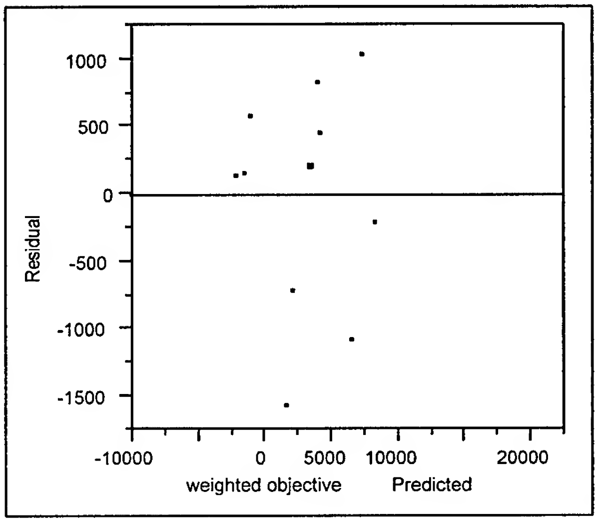
Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Aircraft1	1	1	72019961	65.8970	0.0002
Aircraft2	1	1	1785068	1.6333	0.2485
Aircraft3	1	1	25482135	23.3157	0.0029
Aircraft2*Aircraft3	1	1	13007898	11.9020	0.0136

Whole-Model Test

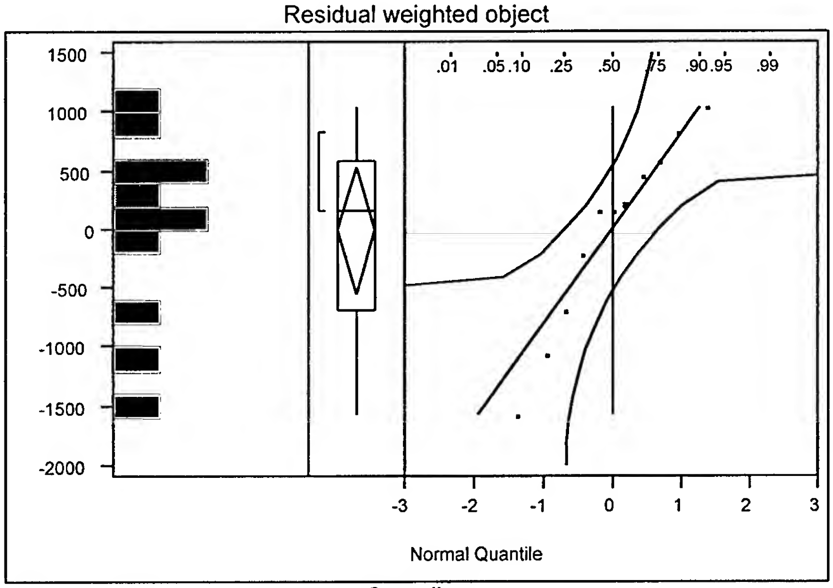


Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	4	127597945	31899486	29.1875
Error	6	6557500	1092917	Prob>F
C Total	10	134155444		0.0005



Residual weighted object



Quantiles

maximum	100.0%	1048.8
	99.5%	1048.8
	97.5%	1048.8
	90.0%	1008.0
quartile	75.0%	591.2
median	50.0%	173.0
quartile	25.0%	-691.7
	10.0%	-1459.2
	2.5%	-1559.7
	0.5%	-1559.7

minimum	0.0%	-1559.7

Moments

Mean	0.0000
Std Dev	809.7839
Std Error Mean	244.1590
Upper 95% Mean	544.0237
Lower 95% Mean	-544.0237
N	11.0000
Sum Weights	11.0000

Test for Normality
Shapiro-Wilk W Test

W	Prob<W
0.940458	0.5044

Appendix 6: Objective Value Average By Aircraft Type

Number of Aircraft	Type of Aircraft A1	A2	A3	A4	A5
0	-32.11742424	**595.6432**	**127.8956386**	-602.596	**212.3323**
1	-620.5530303	**805.3023**	**974.8809524**	-2176.33	**531.1296**
2	-62.88571429	**1092.8**	**-121.4733333**	-1326.79	**-245.548**
3	38.72727273	-457.8	**174.9416667**	-374.471	**32.17778**
4	-371.6621622	205.9097	-97.58928571	-775.897	**735.25**
5	-220.2356322	508.4386	-752.6018519	**1073.56**	-2034.32
6	**-127.3133333**	-367.765	-130.5238095	**52.4023**	-1804.62
7	**191.5944444**	-1414.72	619.1875	**557.0625**	-4146
8	**-273.3733333**	-156.167	-544.7651515	**629.7105**	-2462.23
9	-549.3431373	-192.833	-581.8181818	-520.005	-4707.53
10	388.7971014	365.625	-358.8452381	570.1739	-3346.88
11	948.7111111	-1055.29	-528.1666667	-1033.01	-3167.42
12	-2512	492.8333	-1360.833333	793.75	-3171.47
13	-290.2708333	-1944.92	-132.8333333	-1038.55	-3821.13
14	-367.6212121	-992.667	134.5606061	-1732.01	-5578.44
15	142.1833333	-1941.6	-155.5333333	-775.083	4414.556
16	-660.6060606	591.0714	-176.0625	-1417.89	-2543.08
17	-34.375	-1178.35	-4926.619048	-911.716	-255.444
18	-368.3181818	-2566.22	-2837.916667	1507.808	-1231.88
19	-1475.65	-1143.3	-2002.333333	-2136.88	-1681.88
20	-362.1041667	-926.375	-2286.125	317.9444	-2302.28
21	-521.9761905	98.84848	-1198.515152	-1841.1	-1789.98
22	-2375.384615	-536.806	-2586.666667	-5.52083	-3593.89
23	-3204.083333	-1941.14	-1707.5	-1512.31	303.7667
24	-1023.583333	651.1458	1171.458333	1237.389	-8055.17
25	-2862.766667	-2405.61	-601.6666667	1266.028	-2434.58
26	-1796.962963	-933.796	-1600.333333	-388.296	-2577.2
27	-925.7	-2525.25	-1116.638889	38.95833	-1213.08
28	-5230.958333	-1414.03	**505.1666667**	-120.5	-1670.75
29	-3203.066667	1895.083	**2321.25**	-663.7	-1824.08
30	-1238.916667	118.75	**330.25**	-1857.87	-2319.57
31	-342.9166667	-374.867	-2661.916667	-200.667	-767.3
32	-1996.722222	-2762.42	-3557.681818	-1366.32	-3335.61
33	-3238.333333	-9002.83	-4805.733333	-2859.12	-4110.5
34	-3602.277778	-2706.07	-4395.777778	-2294.19	-665.083
35	-4036.611111	-4316.5	-659.75	-4154.56	-3836.5
36		-3928	-4169.055556	-3501.11	-4142.14
37	-1205.166667	-1891.03	-1889.722222	-1069.38	-1534.9
38	-647.0833333	-5010.08	-3282.212121	-6068.58	-2916
39	-6823.333333	-7969	-5796.694444	-3970.96	-1544.03
40	-4604.388889	-2135.72	-4601.444444	-10639.2	-1822.88
41	-4676.5	-5187.57	-3863.233333	-4550.21	-1465.23
42	-2935	-3216.63	-3295.055556	-2047.75	-3862.62
43	-7308.666667	-3568.87	-4318.75	-2147.83	-2997.83
44	-815.1666667	-3785.83	-1888.145833	-2037.88	-2922.33

45	-4054.142857	-2117.9	-3016.625	-1450.26	-5941.89
46	-7486.25	-1898.42	-2865.888889	-2328.92	-4683.83
47	-5013.166667	-5517.73	-3967.018519	-7384.77	770.9444
48	-5393.708333	-1734.5	-1241.25	-5382.46	-4072.17
49	-3389.458333	-4776	-3609.833333	-9036.92	-1230.67
50	-6167.166667	-879.722	-2071	-5099.92	512.0833
51	-6872	-5338.78	-2503.375	-6417.5	-5363
52	-2559.333333	-4167.94	-35.58333333	-4928.42	-2233.98
53	-1942.722222		-3330.979167	-3727.86	-1586.08
54	-5585.666667	-3605.67	-7353.083333	-8630.67	394.5
55	-4310.166667	-6998.78	-4767		-1197.25
56	-6649.8	-4331.17	-4501.75	-4934.38	-3704.97
57	-5370.5	-6390.78	-11622.33333		-2048.83
58	-1350.3	-5118.03	-4045.583333		-2055.83
59	-3384.642857	-5344.86	-4101.541667	-8532.67	-718.63
60	-4998.619048	-4625.34	-3541.796296		-1686.29
61	-4428.407407	-7627.07	-5290.095238	-4865.67	-2695.17
62	-4598.6875	-3351.97	-4761.8	-7915.6	
63	-6328.890351	-5316.25	-6364.425	-4983.59	-4036.31

Appendix 7: Bennett's Controller Interface

```
@echo off
rem ***
rem ***          File: master.bat
rem ***
rem **           Multi-Scenario batch File
rem **
rem **           Written by:  Barry D. Bennett Jr.
rem **
rem **           Language:  DOS
rem **
rem **
rem ********************************
rem ** Change aircraft numbers in datacft module of gams_in.txt
rem ********************************
call modify
rem ********************************
rem **   setup scenario input files and run scenario 1
rem ********************************
copy msndat1.txt msndat.txt
copy profile1.txt profiles.txt
copy profwx1.txt profwx.txt
rem **
rem ** Call scenario 1 batch file
rem **
call t1_batch
rem ** output to -a00
rem ********************************
rem ***   setup scenario input files and run scenario 2
rem ********************************
copy msndat2.txt msndat.txt
copy profile2.txt profiles.txt
copy profwx2.txt profwx.txt
rem **
rem **
rem ** Call scenario 2 batch file
rem **
call t2_batch
rem ** output to -a01
rem ********************************
rem ***  setup scenario input files and run scenario 3
rem ********************************
copy msndat3.txt msndat.txt
```

```
copy profile3.txt profiles.txt
copy profwx3.txt profwx.txt
rem **
rem **
rem ** Call scenario 3 batch file
rem **
call t3_batch
rem ** output to -a02
rem ********************************
rem ***   Collect run data and calculate value function
rem ********************************
call objvalue
rem **
rem **  *END OF Multi-Scenario BATCH RUN
*****************************************
exit
```

```
rem *******************************************
rem ***        File: t1_batch.bat
rem ***
rem **         Scenario 1 batch File
rem **
rem **         Written by:  Barry D. Bennett Jr.
rem **
rem **         Language:  DOS
rem **
rem *******************************************
rem **
rem **  Add new force structure info to gams input file
rem **
rem **
copy oneA.txt+newslug.txt+oneB.txt gams_in.txt
rem **
rem **
copy budg00_1.txt budg00.txt
copy budg01_1.txt budg01.txt
copy budg02_1.txt budg02.txt
rem **
cd\cfam99~1\runfiles
rem ***************************************
rem ** Conduct the CFAM run
rem ***********************************
gams qstrikeg
rem **
rem ***********************************
rem ** Save the CFAM run output files
rem ***********************************
copy c:\cfam99~1\outfiles\acc2.csv c:\cfam99~1\outfiles\acc2-a00.csv
copy c:\cfam99~1\outfiles\form2.csv c:\cfam99~1\outfiles\form2-a01.csv
copy c:\cfam99~1\outfiles\solvar2.csv c:\cfam99~1\outfiles\solvar2a.csv
copy c:\cfam99~1\outfiles\sum2.csv c:\cfam99~1\outfiles\sum2-a00.csv
copy c:\cfam99~1\outfiles\time2.csv c:\cfam99~1\outfiles\time2-a0.csv
rem **
rem **
cd\cfam99~1\infiles
rem **  *END OF BATCH RUN ******************************************
```

```
rem *******************************************
rem ***        File: t2_batch.bat
rem ***
rem **         Scenario 2 batch File
rem **
rem **         Written by:  Barry D. Bennett Jr.
rem **
rem **         Language:  DOS
rem **
rem *******************************************
rem **
rem **  Add new force structure info to gams input file
rem **
copy twoA.txt+newslug.txt+twoB.txt gams_in.txt
rem **
rem **
copy budg00_2.txt budg00.txt
copy budg01_2.txt budg01.txt
copy budg02_2.txt budg02.txt
rem **
cd\cfam99~1\runfiles
rem ***************************************
rem ** Conduct the CFAM run
rem ***********************************
gams qstrikeg
rem **
rem ***********************************
rem ** Save the CFAM run output files
rem ***********************************
copy c:\cfam99~1\outfiles\acc2.csv c:\cfam99~1\outfiles\acc2-a01.csv
copy c:\cfam99~1\outfiles\form2.csv c:\cfam99~1\outfiles\form2-a1.csv
copy c:\cfam99~1\outfiles\solvar2.csv c:\cfam99~1\outfiles\solvar2b.csv
copy c:\cfam99~1\outfiles\sum2.csv c:\cfam99~1\outfiles\sum2-a01.csv
copy c:\cfam99~1\outfiles\time2.csv c:\cfam99~1\outfiles\time2-a1.csv
rem **
rem **
cd\cfam99~1\infiles
rem **  *END OF BATCH RUN ******************************************
```

```
rem *********************************************
rem ***         File: t3_batch.bat
rem ***
rem **          Scenario 3 batch File
rem **
rem **          Written by:  Barry D. Bennett Jr.
rem **
rem **          Language:  DOS
rem **
rem *********************************************
rem **
rem **
rem **  Add new force structure info to gams input file
rem **
c:
cd\cfam99~1\infiles
copy threeA.txt+newslug.txt+threeB.txt gams_in.txt
rem **
rem **
copy budg00_3.txt budg00.txt
copy budg01_3.txt budg01.txt
copy budg02_3.txt budg02.txt
cd\cfam99~1\runfiles
rem ****************************************
rem ** Conduct the CFAM run
rem *************************************
gams qstrikeg
rem **
rem *************************************
rem ** Save the CFAM run output files
rem *************************************
copy c:\cfam99~1\outfiles\acc2.csv c:\cfam99~1\outfiles\acc2-a02.csv
copy c:\cfam99~1\outfiles\form2.csv c:\cfam99~1\outfiles\form2-a02.csv
copy c:\cfam99~1\outfiles\solvar2.csv c:\cfam99~1\outfiles\solvar2c.csv
copy c:\cfam99~1\outfiles\sum2.csv c:\cfam99~1\outfiles\sum2-a02.csv
copy c:\cfam99~1\outfiles\time2.csv c:\cfam99~1\outfiles\time2-a2.csv
rem **
rem **
cd\cfam99~1\infiles
rem **  *END OF BATCH RUN *******************************************
```

```
‘ *****************************************
‘ ***   File: modify.exe
‘ ***
‘ **    GAMS input file modification routine.
‘ **
‘ **    This program reads in the new candidate force structures provided by the
‘ **    GENESIS GA and modifies the aircraft numbers in the GAMS input file for the
‘ **    CFAM runs.  CFAM requires that the minimum aircraft number in any aircraft
‘ **    type be one.  To insure this aircraft is not used, a sortie rate of zero is given to that
‘ **     aircraft.
‘ **
‘ **    Written by:  Barry D. Bennett Jr.
‘ **
‘ **    Language:  Visual Basic 6.0
‘ **
‘ *****************************************
Private Sub Form_Load()
  Dim txt As String
  Dim Acft() As String
  Dim AcftType As String
  Dim Acft8 As String, Acft9 As String, Acft10 As String, Acft18 As String
  Dim Acft19 As String
  Dim A() As String
  Dim B() As String
  Dim I As Integer
  Dim J As Integer
  Dim X As Integer
  Open "C:\Cfam99~1\Infiles\oldslug.txt" For Input As #1
  Open "C:\Cfam99~1\Infiles\numacft.txt" For Input As #2
  Open "C:\Cfam99~1\Infiles\newslug.txt" For Output As #3
  Open "C:\Cfam99~1\Infiles\tempmod.txt" For Output As #4
‘ **
‘ **  Read in the aircraft numbers from the new force structure
‘ **
  Line Input #2, AcftType
  Acft = Split(SuperTrim(AcftType))
  For k = LBound(Acft) To UBound(Acft)
    If k = 0 Then Acft8 = Acft(k)
    If k = 1 Then Acft9 = Acft(k)
    If k = 2 Then Acft10 = Acft(k)
    If k = 3 Then Acft18 = Acft(k)
    If k = 4 Then Acft19 = Acft(k)
  Next k

   Print #4, Acft8, Acft9, Acft10, Acft18, Acft19
```

```
' ***
' **    Read in aircraft number data table from current section of the GAMS input file.
' **    Modify it to reflect change in aircraft numbers and write the changed lines into a
' **    new file.
' ***

    Do Until EOF(1)
      Line Input #1, txt
      A = Split(SuperTrim(txt))
      B = Split(A(LBound(A)), ".")
      Print #4, txt
      For k = LBound(A) To UBound(A)
        Print #4, "k= ", k, "A(k)=", A(k), "B(k)=", B(k)
      Next k
      If B(2) = "T1" Then
        If B(1) = "8" Then
          If Acft8 = "0" Then
            Print #3, A(0); Tab(19); "1"; Tab(29); "0.0000"
          Else
            Print #3, A(0); Tab(19); Acft8; Tab(29); A(2)
          End If
        ElseIf B(1) = "9" Then
          If Acft9 = "0" Then
            Print #3, A(0); Tab(19); "1"; Tab(29); "0.0000"
          Else
            Print #3, A(0); Tab(19); Acft9; Tab(29); A(2)
          End If
        ElseIf B(1) = "10" Then
          If Acft10 = "0" Then
            Print #3, A(0); Tab(19); "1"; Tab(29); "0.0000"
          Else
            Print #3, A(0); Tab(19); Acft10; Tab(29); A(2)
          End If
        ElseIf B(1) = "18" Then
          If Acft18 = "0" Then
            Print #3, A(0); Tab(19); "1"; Tab(29); "0.0000"
          Else
            Print #3, A(0); Tab(19); Acft18; Tab(29); A(2)
          End If
        ElseIf B(1) = "19" Then
          If Acft19 = "0" Then
            Print #3, A(0); Tab(19); "1"; Tab(29); "0.0000"
          Else
            Print #3, A(0); Tab(19); Acft19; Tab(29); A(2)
          End If
        Else
```

```
            Print #3, A(0); Tab(19); A(1); Tab(29); "0.0000"
          End If
        Else
          Print #3, A(0); Tab(19); A(1); Tab(29); A(2)
        End If

      Loop
    Close #1
    Close #2
    Close #3
    Close #4
    End
End Sub
' ***********************************
' **
' **  Subroutine to reduce the number of blank spaces between words on a line of text to
' **  one.
' **
' ***********************************
Public Function SuperTrim(TheString As String) As String
    Dim temp As String, DoubleSpaces As String
    DoubleSpaces = Chr(32) & Chr(32)
    temp = Trim(TheString)
    temp = Replace(temp, DoubleSpaces, Chr(32))
    Do Until InStr(temp, DoubleSpaces) = 0
      temp = Replace(temp, DoubleSpaces, Chr(32))
    Loop
    SuperTrim = temp
End Function

' *********** End of Modify.exe program *********************
```

```
' ****************************************
' ***  File: objvalue.exe
' ***
' **   Force structure objective value evaluation routine.
' **
' **   This program reads in the results of the three CFAM scenario runs and
' **   calculates 1) the objective value for each scenario, and 2) the objective value
' **   for the multi-scenario. It outputs the multi-scenario evaluation to a file called
' **   evalue.txt for use by the GENESIS GA. It also outputs a summary of the
' **   structure evaluation to a file called report.txt. This one line summary includes the
' **   evaluated force structure, the three scenario objective function values, and the
' **   total multi-scenario objective function value.
' **
' **   Written by: Barry D. Bennett Jr.
' **
' **   Language: Visual Basic 6.0
' **
' ****************************************

Private Sub Form_Load()
   Dim txt As String
   Dim Acft() As String
   Dim AcftType As String
   Dim temp() As String
   Dim D(15) As Double
   Dim C() As String
   Dim A() As String
   Dim B() As String
   Dim O As Double, O1 As Double, O2 As Double, O3 As Double
   Dim I As Integer, J As Integer, L As Integer, LM As Integer, Atotal As Integer
   Dim C1 As Integer, C2 As Integer, C3 As Integer
   Dim Acft8 As Integer, Acft9 As Integer, Acft10 As Integer, Acft18 As Integer
   Dim Acft19 As Integer
   Open "C:\Cfam99~1\Outfiles\acc2-a00.csv" For Input As #1
   Open "C:\Cfam99~1\Outfiles\acc2-a01.csv" For Input As #2
   Open "C:\Cfam99~1\Outfiles\acc2-a02.csv" For Input As #3
   Open "C:\Cfam99~1\Outfiles\Object.txt" For Output As #4
   Open "C:\Cfam99~1\Infiles\tempobj.txt" For Output As #8
   Open "C:\Cfam99~1\Infiles\numacft.txt" For Input As #6
   Open "C:\Cfam99~1\Infiles\evalue.txt" For Output As #7
   Atotal = 0
   I = 0
```

```
'********************************
' **
' **  Calculate total number of Aircraft in Force Structure
' **
'********************************
  Line Input #6, AcftType
  Acft = Split(SuperTrim(AcftType))
  For k = LBound(Acft) To UBound(Acft)
     If k = 0 Then Acft8 = Acft(k)
     If k = 1 Then Acft9 = Acft(k)
     If k = 2 Then Acft10 = Acft(k)
     If k = 3 Then Acft18 = Acft(k)
     If k = 4 Then Acft19 = Acft(k)
  Next k
  Atotal = Acft8 + Acft9 + Acft10 + Acft18 + Acft19

  Print #4, "Total number of Aircraft =", Atotal

'*************************************
' **
' **  Calculate Scenario 1 Objective Function Parameters
' **
'*************************************

  Do
     Line Input #1, txt
     A = Split(SuperTrim(txt), ",")
      J = LBound(A)
      L = UBound(A)

     If UBound(A) <> -1 Then

        For k = LBound(A) To UBound(A)
           If A(k) = "1.00" Then
              D(0) = A(2)
              C1 = InStr(1, A(3), "YES")
              If C1 <> 0 Then
                 D(1) = 1
              Else
                 D(1) = 0
              End If
              D(2) = A(4)
              D(3) = A(6)
              D(4) = A(8)
           End If
```

```
    Next k
  End If

Loop Until EOF(1)

' ***********************************
' **
' ** Calculate Scenario 2 Objective Function Parameters
' **
' ***********************************

Do
  Line Input #2, txt
  A = Split(SuperTrim(txt), ",")
  J = LBound(A)
  L = UBound(A)

  If UBound(A) <> -1 Then

    For k = LBound(A) To UBound(A)
      If A(k) = "1.00" Then
        D(5) = A(2)
        C1 = InStr(1, A(3), "YES")
        If C1 <> 0 Then
          D(6) = 1
        Else
          D(6) = 0
        End If
        D(7) = A(4)
        D(8) = A(6)
        D(9) = A(8)
      End If

    Next k
  End If

Loop Until EOF(2)
```

```
' ***********************************
' **
' **  Calculate Scenario 3 Objective Function Parameters
' **
' ***********************************

  Do
    Line Input #3, txt
    A = Split(SuperTrim(txt), ",")
     J = LBound(A)
     L = UBound(A)

    If UBound(A) <> -1 Then

      For k = LBound(A) To UBound(A)
        If A(k) = "1.00" Then
          D(10) = A(2)
          C1 = InStr(1, A(3), "YES")
          If C1 <> 0 Then
            D(11) = 1
          Else
            D(11) = 0
          End If
          D(12) = A(4)
          D(13) = A(6)
          D(14) = A(8)
        End If

      Next k
    End If

  Loop Until EOF(3)

' ***********************************
' **
' **     Calculate the three scenario objective values:  O1, O2, O3
' **
' ***********************************

  O1 = (-50 * D(0)) + 10000 * D(1) + 125 * D(2) - 50 * D(3) - 5 * D(4) - 50 * (Atotal)
  O2 = (-50 * D(5)) + 10000 * D(6) + 125 * D(7) - 50 * D(8) - 5 * D(9) - 50 * (Atotal)
  O3 = (-50 * D(10)) + 10000 * D(11) + 125 * D(12) - 50 * D(13) - 5 * D(14) - 50 *
(Atotal)
```

```
‘ ***********************************
‘ **
‘ **      Calculate the multi-scenario objective values:  O
‘ **      using equal probabilities of occurrence for each scenario.
‘ **
‘ ***********************************

   O = (O1 / 3) + (O2 / 3) + (O3 / 3)
   Print #4, "Objective values = ", O1, O2, O3, O

‘ ***********************************
‘ **     Append to file report.txt the analyzed force structure, objective values obtained in
‘ **     each scenario, and the overall objective function value.
                                                                                        ‘ **
‘ ***********************************
   Open "C:\Cfam99~1\Infiles\report.txt" For Append As #5
   Print #5, Acft8; Tab(7); Acft9; Tab(12); Acft10; Tab(17); Acft18; Tab(22); Acft19;
Tab(27); O1; Tab(37); O2; Tab(47); O3; Tab(57); O
   Close #5
   Print #8, Acft8; Tab(7); Acft9; Tab(12); Acft10; Tab(17); Acft18; Tab(22); Acft19;
Tab(27); O1; Tab(37); O2; Tab(47); O3; Tab(57); O

‘ ***********************************
‘ **
‘ **      Write to file evalue.txt the multi-scenario objective function value used by
‘ **      GENESIS GA.
‘ **
‘ ***********************************

   Print #7, O
   Close #1
   Close #2
   Close #3
   Close #4
   Close #6
   Close #7
   Close #8
   End
End Sub
‘ ***********************************
‘ **
‘ **  Subroutine to reduce the number of blank spaces between words on a line of text to
‘ **  one.
‘ **
‘ ***********************************
Public Function SuperTrim(TheString As String) As String
```

```
Dim temp As String, DoubleSpaces As String
DoubleSpaces = Chr(32) & Chr(32)
temp = Trim(TheString)
temp = Replace(temp, DoubleSpaces, Chr(32))
Do Until InStr(temp, DoubleSpaces) = 0
   temp = Replace(temp, DoubleSpaces, Chr(32))
Loop
SuperTrim = temp
                                                            End Function

' *********** End of Objvalue.exe program ******************
```

Appendix 8: Bennett's CFAM Setup

Campaign Phase Goals

Target Class	Phase	Theater 1	Theater 2	Theater 3	Penalty
		Goals			
Defeat Close Forces	1	0.2	0.3	0.4	128
	2	0.6	0.5	0.6	64
	3	0.85	0.8	0.85	64
	4	0.95	0.95	0.95	32
Defeat 2nd Echelon Forces	1	0.2	0.2	0.4	128
	2	0.6	0.4	0.6	64
	3	0.85	0.85	0.85	64
	4	0.95	0.95	0.95	32
Defeat Naval Forces	1	0.3	0.3	0.4	128
	2	0.6	0.6	0.6	64
	3	0.85	0.8	0.85	64
	4	0.95	0.95	0.95	32
Reduce Sortie Capacity	1	0.4	0.4	0.4	128
	2	0.6	0.6	0.6	64
	3	0.85	0.85	0.85	64
	4	0.95	0.95	0.95	32
Degrade Air Defenses	1	0.8	0.8	0.4	128
	2	0.85	0.85	0.6	64
	3	0.9	0.9	0.85	64
	4	0.95	0.95	0.95	32
Degrade Air Control	1	0.6	0.6	0.4	128
	2	0.75	0.75	0.6	64
	3	0.85	0.85	0.85	64
	4	0.95	0.95	0.95	32
Destroy Weapons of Mass Destruction	1	0.2	0.3	0.4	128
	2	0.4	0.5	0.6	64
	3	0.6	0.7	0.85	64
	4	0.95	0.95	0.95	32
Destroy Economic/Military Capacity	1	0.05	0.2	0.4	128
	2	0.1	0.4	0.6	64
	3	0.4	0.8	0.85	64
	4	0.85	0.95	0.95	32
Destroy Leadership Sites	1	0.5	0.5	0.4	128
	2	0.75	0.75	0.6	64
	3	0.85	0.85	0.85	64
	4	0.95	0.95	0.95	32
Destroy Lines of Communication	1	0.4	0.4	0.4	128
	2	0.6	0.6	0.6	64
	3	0.85	0.85	0.85	64
	4	0.95	0.95	0.95	32

Campaign Phase Switch Settings

	Theater1	**Switch (Y/N)**			
Class ID	**Target Class**	**Phase1**	**Phase2**	**Phase3**	**Phase4**
1	Defeat Close Forces	Y	Y		Y
2	Defeat 2nd Echelon Forces	Y	Y	Y	Y
3	Defeat Naval Forces		Y	Y	Y
4	Reduce Sortie Capacity	Y		Y	Y
5	Degrade Air Defenses	Y	Y	Y	Y
6	Degrade Air Control	Y	Y	Y	Y
7	Destroy Weapons of Mass Destruction				Y
8	Degrade Economic/Military Capacity				Y
9	Destroy Leaderships Sites			Y	Y
10	Destroy Lines of Communication	Y	Y	Y	Y

	Theater2	**Switch (Y/N)**			
Class ID	**Target Class**	**Phase1**	**Phase2**	**Phase3**	**Phase4**
1	Defeat Close Forces		Y		Y
2	Defeat 2nd Echelon Forces		Y	Y	Y
3	Defeat Naval Forces		Y	Y	Y
4	Reduce Sortie Capacity	Y	Y		Y
5	Degrade Air Defenses	Y	Y	Y	Y
6	Degrade Air Control	Y	Y	Y	Y
7	Destroy Weapons of Mass Destruction		Y		Y
8	Degrade Economic/Military Capacity				Y
9	Destroy Leaderships Sites			Y	Y
10	Destroy Lines of Communication	Y	Y	Y	Y

	Theater3	**Switch (Y/N)**			
Class ID	**Target Class**	**Phase1**	**Phase2**	**Phase3**	**Phase4**
1	Defeat Close Forces	Y	Y		Y
2	Defeat 2nd Echelon Forces	Y	Y	Y	Y
3	Defeat Naval Forces		Y	Y	Y
4	Reduce Sortie Capacity	Y			Y
5	Degrade Air Defenses	Y	Y	Y	Y
6	Degrade Air Control	Y	Y	Y	Y
7	Destroy Weapons of Mass Destruction				Y
8	Degrade Economic/Military Capacity				Y
9	Destroy Leaderships Sites			Y	Y
10	Destroy Lines of Communication	Y	Y	Y	Y

Theater Targets by Type

Target ID	Elements	Description	Number of Targets by Type Theater 1	Theater 2	Theater 3
1	1	Ferry	1	2	1
2	2	Railroad Yard Choke Point	3	1	2
3	12	Truck Column	2	1	1
4	4	MLRS in Position	2	0	2
5	1	Air to Surface Missile in Travel	1	3	2
6	10	Open Storage, Inert Supplies	1	2	1
7	10	Open Storage, Munitions	2	4	1
8	24	Truck Park	1	0	1
9	16	Bridge Type 1	2	1	2
10	10	Bldg Storage	3	2	1
11	6	Iron/Steel Plant (Blast Furnaces)	2	1	2
12	1	Bldg w/Machine Tools	6	3	4
13	1	Bldg. Manufacturing/ Assembly	3	2	3
14	4	POL, Airfield POL Storage, small	1	3	2
15	1	Bunker, Arch	2	4	8
16	1	Bunker, Aircraft	6	18	12
17	30	POL, Airfield POL Storage	2	3	2
18	1	Runway-A/C Highway Strip	3	6	2
19	1	Runway-Earth Hard Soil	0	0	1
20	1	Runway-Asphalt	2	4	3
21	1	Taxiway-Concrete/Asphalt	2	4	3
22	1	Acft Bunker, Double Shell	10	15	8
23	8	Acft Bunker, Large	2	4	5
24	2	Acft Hanger, Steel	9	20	11
25	1	Taxiway Bridge	0	1	0
26	1	Bridge, Pontoon	0	1	2
27	1	Bridge, Highway	4	5	5
28	1	Bridge, Dual Purpose	3	5	4
29	14	Port Facilities, Cranes	1	0	1
30	1	Marine Facility Tunnel Adit	1	0	2
31	1	Port Facility Transverser	2	1	2
32	6	Transformer Yard Large	2	1	2
33	12	Transformer Yard Small	1	2	1
34	3	POL Pump Station	2	1	2
35	6	POL Storage Tanks Above Ground	2	1	2
36	3	POL Refineries Rupture Kill	1	2	1
37	1	Ship, Carrier	0	0	1
38	1	Ship, Cruiser	3	0	3
39	3	Newer Tank Platoon	20	1	10
40	3	Modern Tank Platoon	5	1	3
41	1	Radar in Open, M-Kill	2	5	3
42	4	SAM Missile System	2	5	5

Target ID	Elements	Description	Number of Targets by Type Theater 1	Theater 2	Theater 3
43	1	Radar, SAM site Msn Kill	5	10	4
44	3	SAM Telars	2	6	6
45	1	Bunker, Command & Control	2	2	3
46	1	Bunker, Generic Sector OPS Center	1	2	3
47	2	Radar, Revetted EW/GCI	1	4	3
48	1	Radar, EW/GCI Site	1	2	3
49	28	Aircraft, Fighter Newer	1	2	3
50	30	Aircraft, Bomber	2	1	1
51	10	Acft, Helicopter	2	1	0
52	7	Acft, Fighter Old	3	2	1
53	420	Personnel, Bivovac/Assembly	1	0	1
54	200	Personnel, Prone	1	0	1
55	31	Modern Tank Column	1	0	1
56	9	SAM, Short Range Fire Unit	2	4	4
57	6	ARTY, SPG in Position K-Kil	3	6	4
58	6	ARTY, XX-mm Twed Field Gun/How	3	2	3
59	31	APC Battalion (BMPs)	1	0	1
60	3	APC Platoon (BMPs)	4	2	3
61	10	APC Column (BMP)	1	0	1
62	1	Radar SAM Short	4	8	6
63	1	Radar, Sam Medium	6	12	8
64	1	SSM, Missile site, one missile in tel	5	11	8
65	5	Bldg. RIC/HSF with 10-25 T crane	1	2	2
66	1	Bldg. Nuclear Research Facility	2	1	2
67	1	Nuclear WPNS Support Bunker	0	0	0
68	1	Nuclear WPNS Support Bunker	0	0	0
69	1	Bunker, Command & Control	3	2	2
70	1	Bunker, Ministry of Defense	1	1	1
		Total Target Entities	1387	727	1413

Scenario Target Distribution by Target Class

Class ID	Target Class	Target Entities Theater 1	Theater 2	Theater 3
1	Defeat Close Forces	313	48	280
2	Defeat 2nd Echelon Forces	558	24	546
3	Defeat Naval Forces	20	1	22
4	Reduce Sortie Capacity	252	336	288
5	Degrade Air Defenses	51	111	98
6	Degrade Air Control	4	12	12
7	Destroy Weapons of Mass Destruction	6	14	10
8	Degrade Economic/Military Capacity	133	147	106
9	Destroy Leaderships Sites	4	3	3
10	Destroy Lines of Communication	46	31	48
	Total Target Entities	**1387**	**727**	**1413**

Theater Targets by Target Class

Target Class:	Defeat 2nd Echelon Forces	Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Included Tgts:	APC Battalion (BMPs)	31	1	0	1
	APC Column (BMPs)	10	1	0	1
	ARTY, xx-mm towed field gun/howitzer	6	3	2	3
	Modern Tank Column	31	1	0	1
	Personnel Bivouac/Assembly	420	1	0	1
	Truck Column	12	2	1	1
	Truck Park	24	1	0	1
	Total Target Entities		558	24	546

Target Class:	Defeat Close Forces	Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Included Tgts:	APC Platoon (BMPs)	3	4	2	3
	ARTY, SPG in position, K-kill	6	3	6	4
	MLRS in Position	4	2	0	2
	Modern Tank Platoon	3	5	1	3
	Newer Tank Platoon	3	20	1	10
	Personnel Prone	200	1	0	1
	Total Target Entities		313	48	280

Target Class:	Defeat Naval Forces	Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Included Tgts:	Marine Facility Tunnel ADIT	1	1	0	2
	Port Facilities Cranes	14	1	0	1
	Port Facility Transverser	1	2	1	2
	Ship, Carrier	1	0	0	1
	Ship, Crusier	1	3	0	3
	Total Target Entities		20	1	22

Target Class:	Degrade Air Control	Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Included Tgts:	Bunker, Generic Sector Ops Center	1	1	2	3
	Radar, EW/GCI Site	1	1	2	3
	Radar, Revetted EW/GCI	2	1	4	3
	Total Target Entities		4	12	12

Target Class:	Degrade Air Defenses	Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Included Tgts:	Bunker, Command & Control	1	2	2	3
	Radar, SAM short	1	4	8	6
	Radar in open, M-kill	1	2	5	3
	Radar, SAM site MSN kill	1	5	10	4
	Radar, SAM medium	1	6	12	8
	SAM Missile System	4	2	5	5
	SAM Telars	3	2	6	6
	SAM, short range fire unit	9	2	4	4
	Total Target Entities		51	111	98

Target Class:	Degrade Economic/Military Capacity	Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Included Tgts:	Bldg, Storage	10	3	2	1
	Bldg, Manufacturing/Assembly	1	3	2	3
	Bldg, Nuclear Research Facility	1	2	1	2
	Bldg, RIC/HSF with 10-25 ton crane	5	1	2	2
	Bldg with machine tools	1	6	3	4
	Iron/Steel Plant (blast furnaces)	6	2	1	2
	Open Storage, Inert Supplies	10	1	2	1
	Open Storage, Munitions	10	2	4	1
	POL Pump Station	3	2	1	2
	POL Refineries, Rupture Kill	3	1	2	1
	POL Storage Tanks, above ground	6	2	1	2
	Transformer Yard, Large	6	2	1	2
	Transformer Yard, Small	12	1	2	1
	Total Target Entities		133	147	106

Target Class:	Destroy Leaderships Sites	Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Included Tgts:	Bunker, Command & Control	1	3	2	2
	Bunker, Ministry of Defense	1	1	1	1
	Total Target Entities		4	3	3

Target Class:	Destroy Lines of Communication	Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Included Tgts:	Ferry	1	1	2	1
	Bridge Type 1	16	2	1	2
	Bridge, Dual Purpose	1	3	5	4
	Bridge, Highway	1	4	5	5
	Bridge, Pontoon	1	0	1	2
	Railroad Yard Chokepoint	2	3	1	2
	Total Target Entities		46	31	48

Target Class:	Destroy Weapons of Mass Destruction	Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Included Tgts:	Air to Surface Missile in travel mode	1	1	3	2
	Nuclear Wpns Support Bunker, earth covered	1	0	0	0
	Nuclear Weapons Support Bunker, earth covered	1	0	0	0
	SSM, Missile Site, one missile on TEL	1	5	11	8
	Total Target Entities		6	14	10

Target Class:	Reduce Sortie Capacity	Target Elements	Theater 1 Targets	Theater 2 Targets	Theater 3 Targets
Included Tgts:	Acft Hanger, Steel	2	9	20	11
	Acft Bunker, Double Shell	1	10	15	8
	Acft Bunker, Large	8	2	4	5
	Aircraft, Helicopters	10	2	1	0
	Aircraft, Bomber	30	2	1	1
	Aircraft, Fighter Newer	28	1	2	3
	Aircraft, Fighter Old	7	3	2	1
	Bunker, Arch	1	2	4	8
	Bunker, Aircraft	1	6	18	12
	POL, Airfield POL Storage, small underground	4	1	3	2
	POL, Airfield POL Storage	30	2	3	2
	Runway - A/C Highway Strip	1	3	6	2
	Runway - Asphalt	1	2	4	3
	Runway - Earth, Hard Soil	1	0	0	1
	Taxiway - Concrete/Asphalt	1	2	4	3
	Taxiway Bridge	1	0	1	0
	Total Target Entities		252	336	288

Weapons Inventory

ID	Description	Inventory
25	Smart Rock Type 1	50,000
26	Smart Rock Type 2	50,000
27	Smart Rock Type 3	50,000
28	Smart Rock Type 4	50,000
29	Smart Rock Type 5	50,000
31	Smart Rock Type 6	50,000
33	Smart Rock Type 7	50,000
34	Smart Rock Type 8	50,000
35	Smart Rock Type 9	50,000
40	Smart Rock Type 10	50,000
41	Smart Rock Type 11	50,000
42	Smart Rock Type 12	50,000
1	Rock Type 1	10,000
2	Rock Type 2	50,000
3	Rock Type 3	50,000
4	Rock Type 4	50,000
5	Rock Type 5	50,000
6	Rock Type 6	50,000
7	Rock Type 7	10,000
8	Rock Type 8	50,000
9	Rock Type 9	10,000
10	Rock Type 10	50,000
24	Rock Type 11	50,000
47	Powered Rock Type 1	50,000
48	Powered Rock Type 2	50,000
49	Powered Rock Type 3	50,000
50	Powered Rock Type 4	50,000
51	Powered Rock Type 5	10,000
52	Powered Rock Type 6	10,000
53	Powered Rock Type 7	50,000
54	Powered Rock Type 8	50,000
55	Powered Rock Type 9	50,000
56	Powered Rock Type 10	50,000
57	Powered Rock Type 11	10,000
58	Powered Rock Type 12	50,000
59	Powered Rock Type 13	50,000
60	Powered Rock Type 14	50,000
61	Powered Rock Type 15	50,000
62	Powered Rock Type 16	50,000

ID	Description	Inventory
43	GBU-Rock Type 1	50,000
44	GBU-Rock Type 2	50,000
45	GBU-Rock Type 3	50,000
46	GBU-Rock Type 4	50,000
11	GBU-Rock Type 5	50,000
12	GBU-Rock Type 6	50,000
13	GBU-Rock Type 7	50,000
14	GBU-Rock Type 8	50,000
15	GBU-Rock Type 9	50,000
16	GBU-Rock Type 10	50,000
17	GBU-Rock Type 11	50,000
18	GBU-Rock Type 12	50,000
19	GBU-Rock Type 13	50,000
20	GBU-Rock Type 14	50,000
21	GBU-Rock Type 15	50,000
22	GBU-Rock Type 16	50,000
23	GBU-Rock Type 17	50,000
30	GBU-Rock Type 18	50,000
32	GBU-Rock Type 19	50,000
36	GBU-Rock Type 20	50,000
37	GBU-Rock Type 21	50,000
38	GBU-Rock Type 22	50,000
39	GBU-Rock Type 23	50,000

Bibliography

Air Force Studies and Analyses Agency. Combat Forces Assessment Model (CFAM) Training Manual. Contract DASW01-94-D-0060 with SRS Technologies ASI Division. Washington DC, 28 August 1997.

Alander, S.T. "On Optimal Population Size of GAs," IEEE Computer Society Press, Proc. Comp Euro 92: 65-70 (1993).

Bai, Dawei, T. Carpenter, and J. Mulvey. "Making a Case for Robust Optimization Models," Management Science, 43(7): 895-907 (1997).

Bankes, S. "Exploratory Modeling For Policy Analysis," Operations Research, 41: 435-449 (1993).

Bankes, Steve, and James Gillogly. Proceedings of the Third Annual Conference on Evolutionary Programming. World Scientific Publishing Co., 1994.

Beasley, D., D. R. Bull, and R.R. Martin. "An Overview of GA: Part 1, Fundamentals," University Computing, 15: 58-69 (1993).

Bennett, B. D. "Robust Multi-Scenario Optimization of an Air Expeditionary Force, Force Structure Applying Genetic Algorithms to the Combat Forces Assessment Model," Masters Thesis, Department of Operational Sciences, Air Force Institute of Technology, AFIT/GOR/ENS/00M-04, 2000.

Brooks, Arthur, Bart Bennett, and Steve Bankes. "A Application of Exploratory Analysis: The Weapon Mix Problem," Military Operations Research, 4(1): 67-80 (1999).

Buckles, B. P., F. E. Petry, and R. L. Kuester. Proceedings of Tools for AI. The Institute of Electrical and Electronic Engineers, Inc, 1990.

De Jong, K. Machine Learning 3. Boston: Kluwer Academic Publishers, 1988.

Doran, Christopher M., and Brita Pekarsky. "General Practitioner's Role in Preventive Medicine: Scenario Analysis Using Smoking as a Case Study," Addiction, 93(7): 1013-1023 (1998).

Droogers, P., and J. Bouma. "Soil Survey Input in Exploratory Modeling of Sustainable Soil Management Practices," Soil Science Society of America Journal, 61(6): 1704-1711 (1997).

Fanni, Alessandra, G. Giacinto, M. Marchesi, and A. Serri. "Tabu Search Coupled with Deterministic Strategies for Optimal Design of MRI Devices," International Journal of Applied Electromagnetics&Mechanics, 10(1): 21-32 (1999).

Gafner, Bruce. "Statistical Enhancements & Validation of a Mix Model Methodology," http://www.informs.org/Conf/SD97/TALKS/WB30.html, 1997.

Glover, F, and Manuel Laguna. Tabu Search. Boston: Kluwer Academic Publishers, 1997.

Glover, F., and J. P. Kelly. "Genetic Algorithms and Tabu Search: Hybrids for Optimization," Computers & Operations Research, 22(1): 111-134 (1995).

Glover, F., David Corney, and Marco Dorigo. New Ideas in Optimization. Cambridge: McGraw Hill Publications, 1999.

Goldberg, D. E. The Proceedings of the Third International Conference on Genetic Algorithms. San Mateo: Morgan Kaufman Publishers, 1989.

Grefenstette, J. J. "Optimization Of Control Parameters For Genetic Algorithms," IEEE Transactions on Systems, Man, and Cybernetics, 16(1): 122-128 (1986).

Grefenstette, J. J., and J. E. Baker. The Proceedings of the Third International Conference on Genetic Algorithms. San Mateo: Morgan Kaufman Publishers, 1989.

Grefenstette, John J. "A User's Guide to GENESIS Version 5.0." Excerpt from unpublished manual. http//www.aic.nrl.navy.mil/galist. October 1990.

Henning, Garth. "A Modeling Launch Vehicle Economics," Aerospace America, 37(3): 36-39 (1999).

Hill, Raymond, and Greg A. McIntyre. "A Methodology for Robust, Multi-Scenario Optimization," Phalanx, The Bulletin of Military Operations Research, 33(3): 27-31 (2000).

Holland, J. H. Machine Learning: An Artificial Intelligence Approach, 2 San Mateo: Morgan Kaufman Publishers, 1986.

Ignizio, J.P. "System Stability: A Proxy for Graceful Degradation," Phalanx, 31(1):6-8 (1999).

Kryger, Lisa, and Jennifer Bubriski. Merriam Webster's Collegiate Dictionary Tenth Edition. Philippines: Merriam Webster, Incorporated 1999.

Laferriere, Richard R. "Army Combat Systems Mix Model Methodology," http://www.informs.org/Conf/SD97/TALKS/WB30.html, 1997.

Lokketangen, Arne, and Fred Glover. "Solving Zero-One Mixed Integer Programming Problems Using Tabu Search," European Journal of Operational Research, 106: 624-658 (1998).

Muller-Merbach, Heiner. "Heuristics and their design: a survey," European Journal of Operational Research, 8(1): 1-23 (1981).

Newton, Michael A., and Peter Guttorp. "Stochastic Modeling of Early Hematopoiesis," Journal of the American Statistical Association, 90(432): 1146-1158 (1995).

Nicholson, T. Optimization in Industry, Vol.1 Optimization Techniques. London: Longman Press, 1971.

Reeves, C. R., and T. Yamada. "Genetic Algorithms, Path Relinking, and the Flowshop Sequencing Problem," Evolutionary Computation, 6(1): 45-61 (1998).

Yost, Kirk A. "Consolidating USAF's Conventional Munitions Models," Military Operations Research, 2(4):53-71 (1996).

Vita

Lt. Bulut was born in Istanbul, Turkey. In 1992, he graduated second in his class from Cagaloglu Anadolu Lisesi, a high school educating primarily in German, where he learned also English and French. He entered the Turkish Air Force Academy same year. In 1994, he took his gliding training in Ontario, Canada. He graduated first in his class from the Academy with a Bachelor of Science degree in Computer Science in August 1996. In 1998, he delivered the valedictory in the graduation ceremony of the flight school in Izmir, Turkey. He finished his F-4E Combat Training Course the same year. His first assignment was as a wingman at the 172^{nd} All Weather Interception Squadron, Malatya, Turkey, September 1998. In August of 1999, he entered the Graduate Operations Research Program, School of Engineering and Management, Air Force Institute of Technology, Wright-Patterson AFB, Ohio.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From – To)*
20-03-2001	Master's Thesis	Jun 2000-Mar 2001

4. TITLE AND SUBTITLE
ROBUST MULTI-SCENARIO OPTIMIZATION OF AN AIR EXPEDITIONARY FORCE FORCE STRUCTURE APPLYING SCATTER SEARCH TO THE COMBAT FORCES ASSESSMENT MODEL

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Bulut, Gokay, 1st Lieutenant, TuAF

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)
Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/ENS)
2950 P Street, Building 640
WPAFB OH 45433-7765

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GOR/ENS/01M-05

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Dayton Area Graduate Studies Institute
ATTN: Dr. Frank Moore
3155 Research Blvd, Suite 205
Kettering, OH, 45420

10. SPONSOR/MONITOR'S ACRONYM(S)
DAGSI

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
'Modern Times' bring change in all areas of life. Even the rate of change has changed, and is still changing to increase it's enormous speed even more. Newer and more challenging questions face the military analysts everyday putting a question mark at the end of their last answer. Recently, the question of how to structure a robust air force to meet the requirements of competing, uncertain future scenarios has been keeping them busy. The new world order does not tolerate only being able to respond to a single scenario anymore, which once was considered a hard problem . Who knows what comes next?

In this thesis, we propose a robust optimization methodology to provide an answer to the multi-scenario optimization problem. The methodology employs a meta-heuristic, Scatter Search, to guide the search of the multi-scenario solution space obtained by the evaluations of CFAM, the model currently used to respond to single theater scenario objectives. A Visual Basic\DOS routine performs the necessary interactions to find an AEF strike force robust across three notional threat scenarios.

15. SUBJECT TERMS
Multi-Scenario Optimization, Scatter Search, Force Planning

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Lt. Col Raymond Hill
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU	125	(937) 255-6565, ext 4323, Ray.Hill@afit.edu